REMOTE SENSING AND ARCHAEOLOGY: POTENTIAL FOR THE FUTURE

Report on a Conference, March 1-2, 1984

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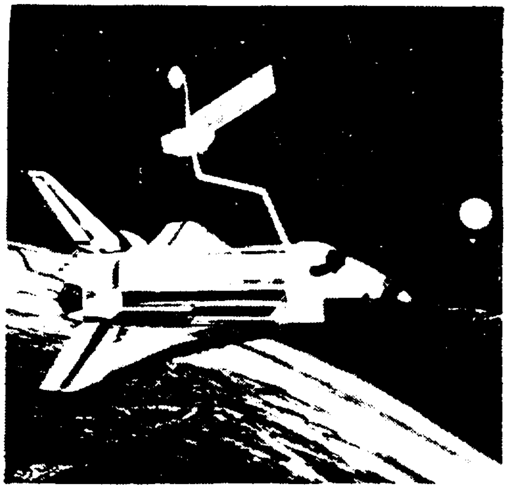

by Thomas Sever
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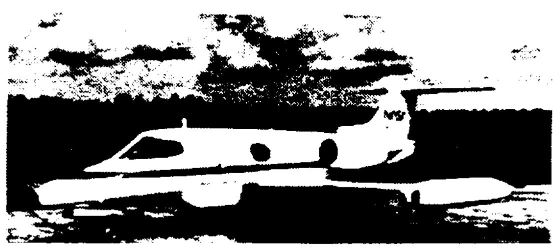

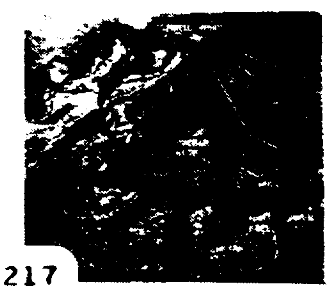

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National Aeronautics and
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EARTH RESOURCES LABORATORY

CONFERENCE ON REMOTE SENSING:

POTENTIAL FOR THE FUTURE

BY

THOMAS SEVER

AND

JAMES WISEMAN

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
EARTH RESOURCES LABORATORY
NATIONAL SPACE TECHNOLOGY LABORATORIES
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FOREWORD

This report documents the Conference on Remote Sensing in Archaeology held March 1 and 2, 1984, at the NASA National Space Technology Laboratories' Earth Resources Laboratory. Twenty-two professional archaeologists attended the session to learn more about the recent advances in NASA's remote sensing technology and to discuss future applications of that technology in archaeology. The conference was funded by NASA, the National Science Foundation, and the National Geographic Society. Discussions and presentations are summarized in this report.

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LIST OF PLATES

I. INTRODUCTION

This document constitutes a report on the Conference on Remote Sensing in Archaeology, which was held March 1-2, 1984, at the Earth Resources Laboratory (ERL) located at the National Space Technology Laboratories (NSTL), Mississippi. The primary purposes of the Conference were to bring together a group of archaeologists representing a broad spectrum of archaeological concerns to learn more about the recent advances in NASA's remote sensing technology and to discuss possible future applications of that technology in archaeology. The Conference, jointly funded by NASA, the National Science Foundation (Grant No. BNS 8409501), and the National Geographic Society, was attended by 22 professional archaeologists (see Plate 1 and Appendix A). The two authors of this report served as co-hosts of the Conference and were members of the Organizing Committee.

The concept of the Conference grew out of a series of discussions between ERL scientists and small groups of archaeologists who visited the ERL in 1983. All the visits were inspired by conversations with Thomas Sever, NASA archaeologist. In June, 1983, James Wiseman made his first visit to ERL with two colleagues from Boston University, Professor Richard S. MacNeish of the Department of Archaeology and Professor William Henneman of the Department of Computer Science, and Professor Elizabeth R. Gebhard, an archaeologist in the Department of Classics at the University of Illinois at Chicago. Their mission was to explore the possible extent of archaeological applications of the remote sensing capabilities of NASA. They came away from the visit convinced that the new technologies to which they were introduced may represent the kind of scientific breakthrough for archaeology in the second half of the 20th century that radiocarbon dating was in the first half of the century.

The almost untapped potential that remote sensing, coupled with computer-enhanced graphics and analysis, holds for the study of the evolution of human cultures seemed beyond measure to them and to other archaeologists who visited the laboratory. It also seemed clear that basic archaeological survey, at least, would in the future be radically altered by remote sensing, and that programs of broader scope than ever before envisioned were now possible.

Discussions by MacNeish and Wiseman with several archaeologists across the country followed. As a result of these discussions and visits, the Coordinating Council of National Archaeological Societies (CCONAS) formed a committee to explore with NASA possible joint activities that would involve the application of remote sensing technology in archaeological research. (CCONAS is made up of officers of the national archaeological organizations, thereby representing a combined membership of over 20,000, including all the professional archaeologists in the United States.) This ad hoc Committee was composed of Dr. William Fitzhugh, archaeologist at the Smithsonian Institution; Dr. George Stuart, staff archaeologist of the National Geographic Society; Dr. John Yellen, Director of the Anthropology Program of NSF; and Wiseman, who served as coordinator of the committee's activities.

The Committee met in December 1983 with Dr. S. G. Tilford, Director of NASA's Earth Science and Applications Division, and other representatives of NASA, including D. W. Mooneyhan, Director of ERL. The meeting had a number of positive results, including general agreement on several basic issues. One important area of agreement was that NASA and the archaeological community should become involved in joint research. Funding for the remote sensing components of archaeological projects would be considered by NASA, and a variety of suggestions were made for an expansion of joint research in the future.

CONFERENCE PARTICIPANTS

PLATE 1

Left to Right *Joe Seger, Daniel Gross, Eugene Sterud, Thomas Jacobsen, Glyn Isaac, Gordon Willey, John Yellen, Richard MacNeish, Charles McGimsey III, Robert McC. Adams, Carole Crumley, George Frison, Cynthia Irwin-Williams, James Wiseman, George Rapp, William Adams, Patty Jo Watson, James Muhly (rear), Bert Salwen, J. Wilson Myers, Ken Langran, Larry Banks, William Fitzhugh, and Thomas Sever.*

The Committee, at the invitation of NASA, encouraged principal investigators of two NSF-funded projects to develop proposals jointly with ERL for applications of remote sensing technology that supplemented and enhanced their established research designs. Immediate visits to ERL by directors of the two projects were made possible by research enhancement grants from NSF, the two proposals were developed, and both were subsequently funded by NASA. The two projects thus enhanced are led by Professor Payson Sheets (University of Colorado) for research in Costa Rica, and Professors Glyn Isaac (Harvard University) and Frank Brown (University of Utah) for investigations in east Africa. The Committee encouraged these projects because they were determined to be especially appropriate for providing tests of applications of remote sensing technology to archaeological problems and had already been given excellent marks for their basic proposals and research designs through the NSF peer-review process. What is more, both projects involved regional surveys in areas for which a considerable amount of remote sensing data already existed: both areas were covered by Seasat images and one would also benefit from data gathered by the Shuttle Imaging Radar (SIR-A) and the Landsat Thematic Mapper (TM).

During the course of the meeting in December, Tilford agreed that in the future archaeologists would be invited to serve on Peer-Review Committees that consider archaeological proposals; invited the Committee to review the paths of the scheduled 1984 Shuttle flight when that information became available in order to consider whether or not those paths coincided with any current archaeological projects that might benefit from the SIR-B data; and indicated that an archaeologist might be appointed to the Inner Working Group that will be involved in the planning for SIR-C in 1985. Ways to acquaint a greater number of archaeologists and scholars in related disciplines with the potential of the new technology were discussed, and the idea emerged of a conference bringing archaeologists together with experts in remote sensing. At that time Mooneyhan offered the facilities of ERL for the Conference documented in this report. The *ad hoc* Committee accepted the generous invitation and agreed to serve, with Sever, as the Organizing Committee for the Conference. The number of scholars that could reasonably be accommodated at ERL at one time was determined to be 20-25. The Committee later prepared an invitation list that would provide representation from senior scholars working both in the Old World and New World and who are concerned with time periods ranging from the Pliocene to the present day. A proposal for funding the conference was then prepared by the authors of this report.

The purpose of the Conference was to provide the archaeologists both an introduction to remote sensing and examples of applications of the technology by ERL, as well as an opportunity for discussion among themselves of possible applications in archaeology. The agenda (see Appendix B), therefore, called for a series of presentations on the first day by researchers at ERL who would discuss remote sensing applications in a variety of disciplines. Presentations were selected that offered the greatest potential for similar applications in archaeology; they are discussed in detail in Section III. The second day of the Conference was devoted to a round-table discussion, and a number of questions and concerns were circulated with the agenda to help provide a sharper focus for that discussion. A summary of the principal issues considered, comments on them, and action taken by the participants is presented in Section IV. The following appendices have been included to familiarize the reader with remote sensing terminology and research:

Appendix C. Glossary of Terms

Appendix D. Select Bibliography

Appendix E. ERL Publications

This report is the result of collaborative efforts by the authors. Sever was primarily responsible for the composition of Sections II and III and Wiseman for Sections I, IV, and V, but both authors are responsible for the final form of all sections. The sources of the appendices are either self-evident or specified within the text of the appendix.

We are grateful to the National Science Foundation, the National Geographic Society, and the Earth Resources Laboratory for the funding and facilities that made the Conference possible. We thank also Dumbarton Oaks, where the Committee met to lay plans for the Conference; Boston University, which served as the sponsoring institution for the funding grants and which continues to encourage in various ways the development of remote sensing in archaeology; Hester Davis and other members of CCONAS who supported the creation of the Committee; S. G. Tilford and other officials of NASA who have helped to foster the growing relationship between NASA and the archaeological discipline; the scientists at ERL who so generously gave of their time and knowledge to help inform us all about remote sensing; Marjorie Smith, Donna Skipper, and all the others at ERL who handled the logistics of the Conference and made the local arrangements; and Alice Cordella, Administrative Assistant to the Chairman in the Department of Archaeology at Boston University, for both pre- and postconference logistical support. We would like here especially to acknowledge the active encouragement and generous support we have received from Patricia Conner, Chief of the Test and Evaluation Group at ERL, and D. W. Mooneyhan, Director of ERL. Whatever success the Conference may have enjoyed results in large part from their generosity of spirit, wise counsel, and clear perception. All of us in archaeology and remote sensing owe them a deep debt of thanks.

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II. FUNDAMENTALS OF REMOTE SENSING

Remote sensing is the science and art of detecting and recording objects or phenomena from a distance through devices that are sensitive to various bands of the electromagnetic spectrum. In a sense, the eyes are remote sensors inasmuch as they allow man to gather information about his environment without physical contact. The technology of past centuries has produced instruments such as glasses, telescopes, and camera lenses that have extended the range of human vision. These instruments allow man to gather information and subsequently better evaluate his surrounding world. Recent advances in remote sensing technology now promise to make a quantum leap in man's technological capabilities, by allowing him to "see" information that his eyes, themselves, cannot see.

All materials at temperatures above what is known as absolute zero ($-273^{o}C$ or $0^{o}K$) produce electromagnetic radiation in the form of waves. The electromagnetic spectrum is a continuum of electric and magnetic wavelengths that extend from the short cosmic rays of high frequency at one end of the spectrum to long radio waves of low frequency at the other end (Figure 1). The limits of the electromagnetic spectrum are not known and may lie at infinity. Wavelength dimensions are used to bound regions within the spectrum, although a discrete separation does not occur since the wavelengths themselves merge imperceptibly into each other. These regions are referred to as the ultraviolet, visible, near infrared, microwave, etc., portions of the spectrum.

The detection, recording, and analysis of electromagnetic energy constitute the foundation of remote sensing. There is no single instrument that can detect emissions within the entire electromagnetic spectrum. The "visible" region of the spectrum is extremely small since the human eye detects only the

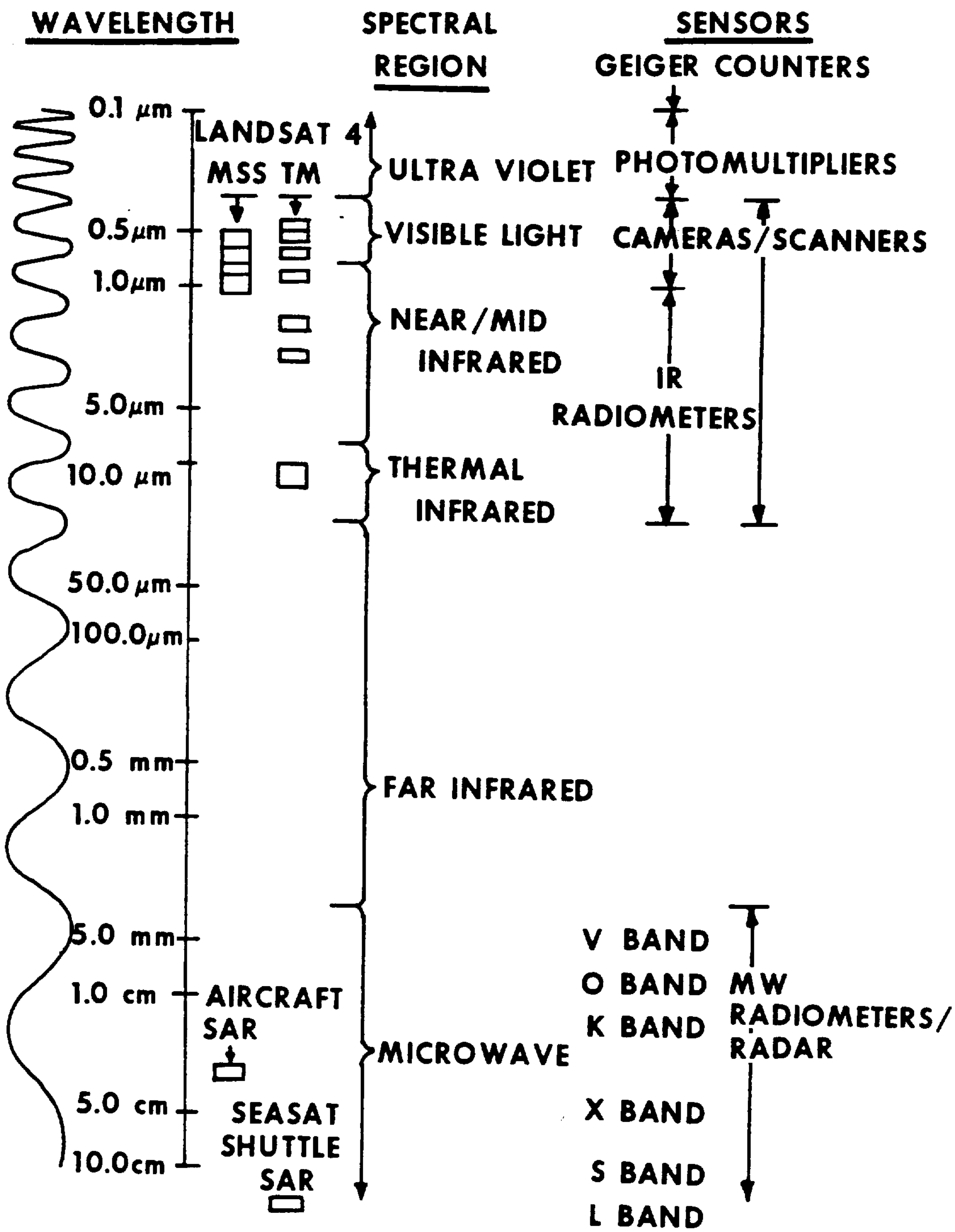


Figure 1. Diagram of the Electromagnetic Spectrum

portion that extends from about 0.4 to 0.77 micrometer. In fact, if the known span of the electromagnetic spectrum were conceived of as analogous to the circumference of the earth, the human eye and conventional film would be able to see only that portion of it that is equal to the diameter of a pencil. In short, man is relatively blind to the universe around him. Despite his limited vision, however, he is constructing instruments whose mechanical eyes can extend his vision and as a result expand his knowledge by "seeing" information previously inaccessible to him.

The recent rapid advancement of remote sensing technology now promises to provide reliable and inexpensive information that can be employed for intensive archaeological and ethnographic investigations. While archaeologists have employed remote sensing analysis in the form of aerial photographs and ground-based instruments in the past, improved remote sensing instruments with greater resolution and more precise bandwidths are now opening the doors to new frontiers in archaeological investigations. Advancements in this area are occurring so fast that unless archaeologists apprise themselves of the technology now, they will be unable to keep pace with the technology in the near future. Moreover, they may find that both developers and pot hunters have once again beaten them to the field.

Before the launch of the Landsat satellite in 1972, aerial photographs were the most familiar form of remote sensor data employed in most environmental studies. While cameras equipped with black and white or color film provide the greatest capability in terms of versatility or high resolution of detail, they nevertheless possess certain liabilities. For instance, they are limited to seeing only what the human eye can see. In addition, they must operate in daylight, during clear weather, on days with minimal atmospheric haze, in order to produce an optimum product. Since cameras are not "real time" systems, a certain time factor is involved for laboratory processing before the resultant images are available for analysis. This time gap can range from several hours to several weeks, as is the case for photographs made by cameras in space vehicles.

Color infrared (CIR) film has improved man's visible range by detecting longer wavelengths somewhat beyond the red end of the light spectrum. CIR film was initially employed during World War II to differentiate objects that had been artificially camouflaged. While CIR film can be successfully employed in studies dealing with vegetational differences, it also is subject to the limitations indigenous to conventional camera systems. Perhaps the major disadvantage for black and white as well as CIR photography is the limited information that can be obtained when compared to modern remote sensing detectors. While photographic systems are the most common types of sensor systems used in archaeological remote sensing investigations to date, they cannot obtain information about the thermal characteristics (temperature and emissivity) of vegetation, soil, and water on the earth surface. Nonphotographic remote sensors, often referred to as scanner systems, are capable, however, of simultaneously collecting data in the visible, infrared, and thermal portions of the electromagnetic spectrum.

Most remote sensing devices gather energy through reflected sunlight. A passive sensor is one that measures radiation originating at or reflected from targets illuminated by natural means. In order to separate a target for study, objects must be differentiated from their background. Passive sensors can be selected whose detectors are responsive to the wavelengths of the target, but less responsive to the radiated energy surrounding the target. Other sensor detectors can be selected that measure heat radiation from the target.

In both situations the energy detected by the sensor is either reflected or emitted by the target.

Active systems, on the other hand, generate their own illumination of the target. Active systems, such as radar, can operate under various weather conditions and can be flown at any time during the day or night. A radar sensor produces its own energy pulse which is directed at a target or study area. In this manner objects or surface cover characteristics are illuminated by the energy pulse and "backscatter" some of the transmitted energy to the receiving antenna of the sensor. The signal that radar sends out may be polarized horizontally or vertically to enhance the images. The radar imagery of an area produced by cross-polarization (Horizontal-Vertical) differs from imagery produced by like-polarization (Horizontal-Horizontal). Radars have varying capabilities since they employ a variety of wavelengths. Longer wavelengths can be used to depict contrasting vegetation types while shorter radar wavelengths seem to ignore vegetation and emphasize the surface beneath. Radar systems can penetrate clouds and are especially beneficial in tropical forest areas where continuous cloud cover precludes use of aerial photography. Radar data can also be successfully employed in desert environments. Shuttle Imagery Radar was used in the Sudanese Desert in 1982 to penetrate the sand to produce images of the underlying geology (Plate 2).

Several different bands of data from the electromagnetic spectrum can be combined to produce multispectral images that can provide accurate identification and information about objects or phenomena within a scene. In a typical multispectral, optical-mechanical scanner system, the energy reflected and emitted from a small area of the earth's surface is "seen" by a scanning mirror and reflected through an optical system. This incoming reflected energy is spectrally dispersed and optically focused on various detectors that are sensitive to various portions of the spectrum. The size of the resolution element is determined solely by the platform altitude since the sensor IFOV is the result of a fixed field stop in the optical system of the scanner. Resolution elements can vary dramatically in size. For instance, the Advanced Very High Resolution Radiometer (AVHRR) satellite has a 1-kilometer resolution while the MOMS airborne sensor is designed to produce a 1-foot resolution.

As the platform passes above the landscape the ground surface is scanned in successive strips, or scan lines, by the mirror. The rotational motion of the mirror allows the energy to be measured, one resolution element at a time, for the complete scan line. The forward motion of the platform, which is perpendicular to the scan line, gathers successive strips of the terrain surface. The rate of rotation of the mirror is adjusted to the velocity of the sensor platforms so that adjoining scan lines do not overlap or leave gaps in the data. Scanner systems gather data at a phenomenal rate. In the case of the Thematic Mapper Simulator (TMS), for example, data are collected at a rate exceeding 50,000 resolution elements per second.

The energy received by the detector varies in signal strength as the resolution elements or pixels (picture elements) of the landscape vary in character. Each pixel is assigned a digital value between 0 and 255 by each detector (for an 8-bit system). A pixel size is determined by the projection of the optical field stop through the optical system to the ground. For instance, an optical system that is field-stopped (baffled) to an angular field-of-view of 10^{-3} radians would produce a ground resolution area of 1 ft. by 1 ft. from an altitude of 1,000 feet. Thus, if a scanner system has 12 detectors, a resolution element on the ground will be "seen" 12 different ways. The output signals from the detectors are recorded on magnetic tape and can be played back later for display on an image display device as tones of

Top Left: *Landsat image of a portion of the Sudanese desert. Note the diagonal band and compare it with the same band in the bottom right.*

Bottom Right: *Prehistoric riverbeds buried beneath the sands of the Sahara as detected by SIR-A. Ground truth reconnaissance revealed the presence at certain localities of Stone Age human artifacts, ostrich shells, and shells of* Zootecus insularis, *a land snail indicative of formerly moist soil and vegetation.*

dark or light, depending on signal strength. The composite of all elements and scan line for each detector renders an image similar to a photo. As a result, images can be produced that would normally be beyond the range of human visibility.

The human eye can discriminate only about 20 to 30 shades of gray under normal viewing situations. Under the same conditions it can discriminate a much larger number of color hues. Remote sensing instruments can gather up to 256 shades of gray in numeric format for each channel of its detection array. In a 12-band scanner system, for instance, up to 3,060 pieces of gray-scale information are available. The same numeric data from a scanner system can be combined to produce millions of color hues of which the human eye can only separate a small proportion. In short, there is more information available than the investigator can "see"; electronic manipulation of the data, however, allows investigators to extract much of the information in a form that can be visualized.

Numeric data are essential for accurate quantitative analysis. Electronic manipulation of the data can increase or decrease emphasis, extract data selectively from the total, determine signature parameters, and examine data characteristics normally not visible on the imagery. The combination of man and computer in an interactive system can lead to the solution of research problems that would otherwise be unattainable.

Three kinds of images may be produced during the analysis sequence: the reconstructed image, the enhanced image, and the classification image. These images may be displayed in black and white or color format on a televisionlike image display device or they may be produced as photographic hard copies.

The reconstructed image is derived from the unaltered data and represents the radiation values of the original ground information. In this fairly routine process numeric data stored on magnetic media are assembled into image format. In this image all pixels retain their raw data value and thus provide a basic rendition of the original ground scene.

The enhanced image represents data that have been improved in order to illustrate features within the data that are of special interest to the investigator. Several enhancement techniques can be used to emphasize selected features within the image. Some of these enhancement techniques include sun-angle correction, density slicing, band ratioing, edge enhancement, synthetic color assignment, and filtering. As a result of image enhancement techniques, features can be extracted through mathematical means to produce detailed information not readily apparent in the raw data image.

In the classified image, spectral signatures are developed to produce various "classes" of information. A spectral signature is a quantitative measurement of the properties of an object at one or several wavelength intervals. In the classification techniques each pixel or group of pixels (depending on the window size selected by the investigator) is analyzed and assigned a spectral signature. Homogeneous signatures are grouped in various categories that are referred to as spectral "classes." By assigning a different color for each class, an image is produced that represents different types of ground information; e.g., water, forest, urban complex, etc. The development of numeric data in an image format not only allows for a visual representation of the results of analysis, it also provides the investigator with easy access to the acreages, percentages, and correlation of the features within the image.

III. EARTH RESOURCES LABORATORY PRESENTATIONS

INTRODUCTION

The first day of the conference was dedicated to presentations by NASA principal investigators of the various capabilities and applications of remote sensing technology. D. W. Mooneyhan, Director of NASA's Earth Resources Laboratory, opened the morning session in the Gainesville Room by welcoming the participants and expressing NASA's interest in working in cooperative projects with the professional archaeological community.

REMOTE SENSING OVERVIEW

The first presentation was by Gene Zetka, Chief of the Technique Development Group, who provided a general overview of remote sensing technology and data analysis techniques. Beginning with an explanation of the electromagnetic spectrum, Zetka explained how information could be detected and recorded in spectral wavelengths beyond the range of human vision. These data are recorded as digital count values and, through various mathematical computations, can produce visual images that accentuate phenomena of special interest to the investigator. Zetka provided a step by step explanation of the various data processing techniques used in remote sensing analysis from the time the data first enter the Laboratory up to the development of a final product.

Data analysis is conducted using a software operating system developed at ERL known as Earth Resources Laboratory Applications Software (ELAS). ELAS is designed to provide a highly flexible package of programs with the processing and analysis power needed in vigorous remote sensing investigations. Table 1 is a partial list of the capabilities and routines contained within ELAS. A

Table 1

DATA PROCESSING AND ANALYSIS CAPABILITIES OF ELAS

ELAS IS A GEOBASED INFORMATION SYSTEM.

UTILITY ROUTINES:

- READ CCT DATA IN EDC P- OR A-TYPE FORMATS
- REFORMAT DATA FROM SELECTED SENSORS INTO COMMON ELAS FORMAT
- JOIN OR OVERLAY DATA FILES TO PRODUCE CONCATENATED DATA SETS
- DESTRIPE LANDSAT MSS DATA TO REMOVE BANDING EFFECTS
- DIGITIZE POINT OR POLYGON DATA FROM MAPS
- COPY AND EDIT DATA

DATA PROCESSING ROUTINES:

- REGISTER MULTITEMPORAL SETS OF DATA (SCENE-TO-SCENE)
- REGISTER DATA SETS TO UTM MAP PROJECTION (SCENE-TO-MAP)
- REGISTER DATA SETS WITH UNEQUAL SIZED PIXELS (E.G., LANDSAT/SEASAT)
- SELECT TRAINING SAMPLES FOR SIGNATURE DEVELOPMENT BY SUPERVISOR OR AUTOMATED UNSUPERVISED TECHNIQUES
- COMPUTE LENGTH OF INTERFACE BETWEEN TWO CATEGORIES
- EDIT AND MERGE STATISTICS
- DISTINGUISH BETWEEN DIFFERENT SIZE CONTIGUOUS AREAS OF THE SAME MATERIAL

CLASSIFICATION ROUTINES:

- CLASSIFY MULTIPLE SURFACE COVER CLASSES:
  --MAXL (2-8 BANDS)
  --M234 (2-4 BANDS, HASH TABLE USED)
  --WMAX - MAXIMUM LIKELIHOOD WITH MASK
- CLASSIFY SINGLE SURFACE COVER CLASSES (NONPARALLELEPIPED):
  --SCATTERGRAMS FOR TRAINING
  --SINGLE-CLASS CLASSIFIER

STATISTICAL ROUTINES:

- PRINCIPAL COMPONENT AND CANONICAL ANALYSIS, REGRESSION/CORRELATION, GOODNESS OF FIT, ETC.

POLYGON MANIPULATION ROUTINES:

- SELECT TRAINING SAMPLES, EDIT DATA, UPDATE DATA, AND EXTRACT ACREAGE

FILTERING ROUTINES:

- CORRECT EXTRANEOUS DATA POINTS
- PERFORM CONTEXT ANALYSIS

CHANGE DETECTION ROUTINES:

- DETECT LOGICAL PATTERN SHIFTS
- DETECT RADIANCE VALUE SHIFTS

DIGITAL TERRAIN MANIPULATION PROGRAMS:

- CONVERT NCIC TAPES TO UTM PROJECTION
- RESAMPLE DATA CELL TO PRODUCE SELECTED CELL SIZES
- COMPUTE ASPECT, PERCENT SLOPE, SLOPE LENGTH, AND AVERAGE SLOPE
- PRODUCE THREE-DIMENSIONAL MAPS OF LAND USE

DATA BASE STORAGE AND RETRIEVAL AND MANIPULATION CAPABILITIES:

- INCORPORATE OTHER TYPES OF DATA WITH LANDSAT DATA IN THE CLASSIFICATION PROCESS (ELEVATION, SLOPE, ASPECT, RAINFALL, ETC.)
- ANALYZE DATA THROUGH ALGORITHMS PROGRAMMED AT RUN TIME THROUGH MODULE DBAS, WHICH USES STANDARD BASIC PROGRAMMING LANGUAGE INSTRUCTIONS
- SELECTED APPLICATIONS ALGORITHMS
- AID IN MODELING

OUTPUT PREPARATION ROUTINES:

- SCALE DATA FOR PRINTING, PLOTTING, OR CRT DISPLAY AS GRAY SHADES OR COLOR-CODED MAPS AT SELECTED SCALES AND MAP PROJECTIONS
- TABULATION OF INFORMATION AS APPROPRIATE

major advantage of ELAS is the ease with which additions and modifications to the software may be made as new techniques are developed.

The presentation continued with a discussion of supervised and unsupervised classification techniques. In the supervised approach, the investigator is required to be familiar with the area and must select training samples that represent each land cover class to be identified. Each training sample must contain all the spectral variations within each surface cover category. In the unsupervised approach the entire data set is examined within limits established by the investigator. Spectral signatures, defining spectrally distinct features, are developed without prior knowledge of ground cover conditions. Both approaches produce final classifications of high accuracy. The selection of the classification approaches is determined by the amount of prior knowledge about the surface available to the investigator.

Since radar or microwave data derived by remote sensing promise to make significant contributions to future archaeological analysis, Zetka included an explanation of the properties and backscattering effects of radar data. Radar data are particularly effective in the detection of linear or geometric patterns. It is important, however, to select the correct radar band for the type of environment being analyzed. L-band radar systems, such as the one used for the SIR-A (Shuttle Imaging Radar) experiment, are preferable in desert environments while X- or C-band radar systems would be more desirable in tropical or jungle environments.

Zetka concluded his presentation by showing how remotely sensed data could be combined with ancillary data such as soils, topography, and hydrology in a data base system to produce information that might not be directly apparent in the remotely sensed data itself. He also explained that different types of remotely sensed information, such as satellite data and radar data, could be combined so that the attributes of both types of data remain in the final composite. Classification results from merged data can thus be complementary and will result in a substantial increase in discrimination accuracy.

SENSORS

Gerry Meeks discussed the various types of satellite, airborne, and ground-based sensors currently available within the NSTL/ERL program. Since 1972 Landsat satellites have been collecting data over the earth's surface. The satellites are in polar, sun-synchronous orbits at an altitude of 920 kilometers. They circle the earth every 103 minutes (14 times a day), with each successive pass occurring 26 degrees to the west. The Multispectral Scanner (MSS), the primary sensor aboard Landsat, provides a continuous series of images of 185-kilometer-wide sections of the earth's surface. The MSS measures reflected light or radiance in the following four wavelength bands: 0.5 to 0.6 micrometer (green), 0.6 to 0.7 micrometer (red), and 0.7 to 0.8 and 0.8 to 1.1 micrometers (both near-infrared). Values of radiance are recorded in each of these four bands for every surface picture element scanned, and they comprise a multispectral data set which is the basis for analysis. The four radiance values for each pixel are used to develop statistics input to a maximum likelihood classifier. The resulting classes are labeled and integrated into a category classification of the surface cover. The accuracy of this classification is verified through photographic interpretation and ground truth missions.

Research into the use of satellite-acquired, remotely sensed digital data has provided investigators with a valuable tool for assessing land cover characteristics and conditions. For the past 11 years the MSS onboard Landsats 1, 2, and 3 has provided synoptic, near-real-time data for large area analysis.

On July 16, 1982, a second-generation earth-sensing satellite, designated Landsat 4, was launched, culminating nearly a decade of development effort, and another (Landsat 5) was launched on March 1, 1984. The Thematic Mapper (TM) is the experimental sensor onboard Landsats 4 and 5 and offers improved spectral and spatial resolution, geometric fidelity, and radiometric accuracy (Table 2). In addition, the TM sensor's eight-bit data precision offers improvements in data quantification as compared to the six-bit data received from the MSS. This increased performance presents new opportunities for the discrimination of land cover, particularly with respect to small surface features.

Airborne sensors are another valuable resource tool for archaeological investigation since they can provide data ranging from 30- to 3-meter resolution. ERL has two operational airborne sensors, the Thematic Mapper Simulator (TMS) and the Thermal Infrared Multispectral Scanner (TIMS), which are flown in the NASA/NSTL Learjet 23 aircraft at altitudes ranging from 6,500 feet to 40,000 feet. During daylight missions CIR photography is simultaneously acquired, with 60% overlap for stereoscopic viewing to aid in digital data analysis. The TMS was initially designed to evaluate the applicability of 30-meter ground resolution and the seven Thematic Mapper spectral bands for various remote sensing applications in anticipation of the operational status of the Landsat 4 TM satellite. TMS data allowed users to understand data characteristics and develop data analysis techniques prior to the availability of data from the satellite-borne system. Although the Landsat TM is now operational, the TMS continues to be used to acquire high-resolution data and to collect data within narrow acquisition windows. Many research investigations at ERL have successfully used TMS data to detect and analyze factors that are

Table 2

SPECTRAL CHARACTERISTICS OF THE THEMATIC MAPPER (TM) SATELLITE

<u>TM SPECTRAL DATA</u>

BAND	SPECTRAL RANGE, m	RADIOMETRIC RESOLUTION	PRINCIPAL APPLICATIONS
1	0.45 to 0.52	0.8% NE	Coastal Water mapping Soil/vegetation differentiation Deciduous/coniferous differentiation
2	0.52 to 0.60	0.5% NE_p	Green reflectance by healthy vegetation
3	0.63 to 0.69	0.5% NE_p	Chlorophyl absorption for plant species differentiation
4	0.76 to 0.90	0.5% NE_p	Biomass surveys Water body delineation
5	1.55 to 1.75	1.0% NE_p	Vegetation moisture measurement
6	10.4 to 12.5	0.5K NETD	Plant heat stress measurement Other thermal mapping
7	2.08 to 2.35	2.4% NE_p	Hydrothermal mapping

NE_p= noise equivalent reflectance

NETD= noise equivalent temperature difference immediately transferable to archaeological research. These investigations include discrimination of small heterogeneous features, soil delineation, geological mapping, geobotanical mapping, vegetational stress assessment, and urban studies.

Perhaps the most promising sensor for future archaeological remote sensing research is the TIMS. The TIMS is a six-channel thermal infrared multispectral scanner capable of measuring target radiation in 400-nanometer intervals from 8.2 through 9.4 micrometers, and in 800- and 1,000-nanometer intervals from 9.4 through 12.2 micrometers. Under laboratory conditions, noise equivalent temperature differentials of 0.05°C to 0.30°C are achievable.

The uniqueness of TIMS lies not only in its thermal IR capability, but also in its multispectral nature. Each of the six bands measures thermal radiation, as temperature in degrees Centigrade, of the target. If thermal radiation were the only contributor to the detected energy, all six bands would produce the same results. The emissivity of the target being overflown, however, is also a contributor to the measured return. Emissivity is the ratio of radiant emission of a source to that of a blackbody at the same temperature. Essentially a measure of the capability of a source to release absorbed energy, emissivity is a function of the type of material and its surface geometry and can vary with both wavelength and the temperature of the material. (Consider an earth scene that absorbs the sun's energy during daylight hours and emits this energy during night hours.) Because the emissivity of any given object is not constant across the 8.2-12.2-micrometer range, slight variations in signal levels, primarily attributable to target emissivity, are in the output data. These small variations allow investigators to determine, by remote means, the apparent spectral emissivity differences of selected targets (Plate 3).

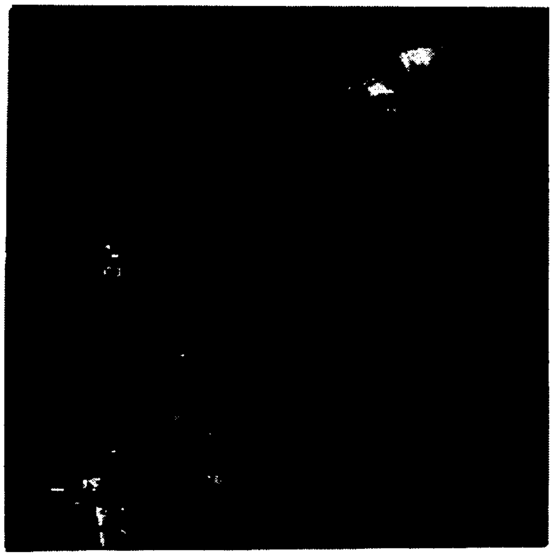
A secondary benefit of TIMS results from its very high thermal sensitivity. High sensitivity was designed into the system because of the small emissivity contribution. With a thermal sensitivity of 0.3^{o}C or less, apparent spectral emissivity detection would be virtually impossible. Consequently, the TIMS consistently produces sensitivities less than or equal to 0.1 degree Centigrade. This capability allows single-band usage for detecting very subtle thermal variations. Detection of boat wakes, thermal effluents, thermal shadows, and archaeological phenomena are examples of this secondary aspect of TIMS.

(The afternoon session was dedicated to presentations by ERL scientists on specific applications of remote sensing technology. The presentations were conducted using image display devices at the ERL computer facility. Although only one presentation was specifically oriented to archaeology, it was immediately apparent how the other applications could be incorporated into archaeological research designs. The eight presentations, summaries of which follow, were selected from a broad range of ERL research activities.)

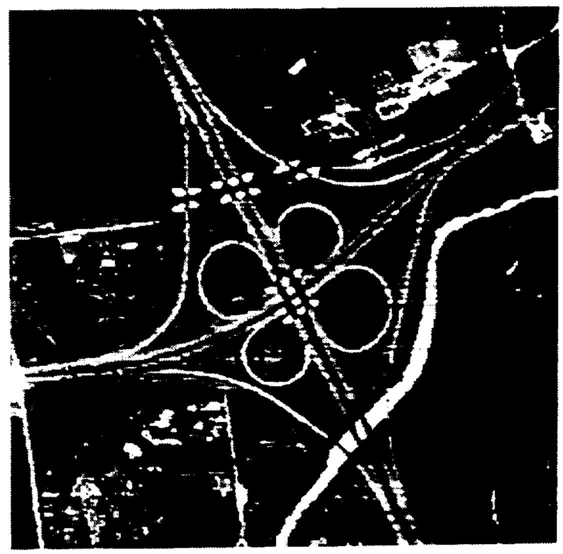
ARCHAEOLOGY

Thomas Sever, ERL archaeologist, presented results to date of an archaeological remote sensing investigation designed to determine the utility of high-resolution satellite digital data, Thermal Infrared Multispectral Scanner data, and Synthetic Aperture Radar (SAR) data in the identification and typing of archaeological sites and features. The practical application of this

TIMS DATA



Channel 3



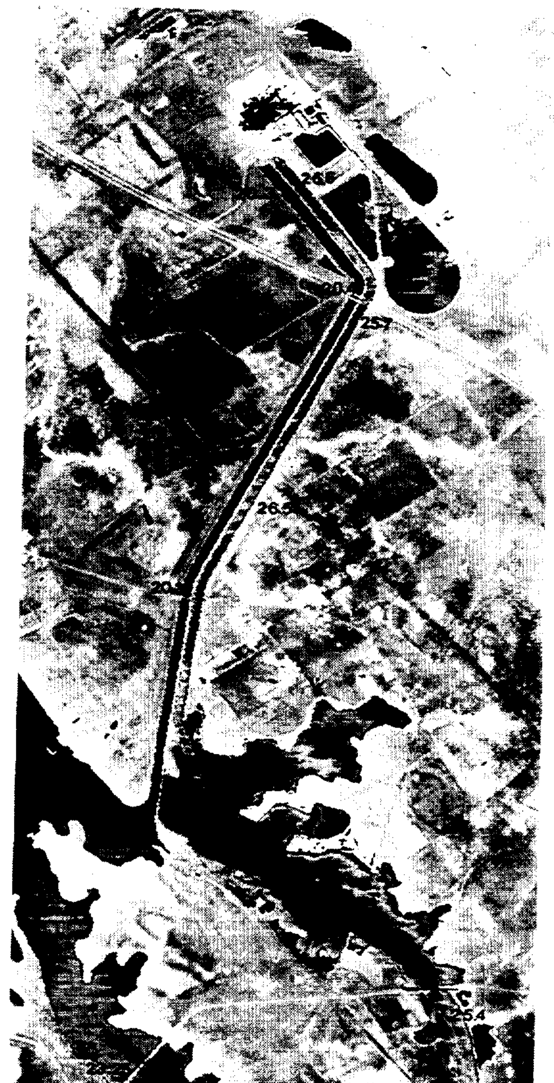
Channel 4

Comparison of TIMS Channels 3 (9.0–9.4 micrometers) and 4 (9.4–10.2 micrometers) acquired at the Interstate 10/U.S. Highway 49 interchange north of Gulfport, Mississippi. Although the surface temperature is the same in both of these simultaneously acquired pre-dawn images, differences arise due to thermal emission property variations in the two wavelength regions sampled by the TIMS for a given target.

Thermal Emissivity

PLATE 3

Thermal IR Data Analysis



This image depicts absolute radiometric water surface temperatures produced through the analysis of night acquired TIMS digital data. The data were collected over a power plant cooling pond in south-east Mississippi. The colors represent water temperature (hot = white, approx. 26.5° C; intermediate = green, approx. 23.5° C; cold = magenta, approx. 20.3° C). The water temperatures of the cooling pond are superimposed on a black and white representation of TIMS raw digital data. Multiple R^2 = 0.97, when floating thermometer data are used as truth (22 points), in a regression against absolute radiometric temperature.

Water Surface Temperature Derived from Night-Acquired TIMS Data technique could expedite survey and excavation activities. In an era of dwindling budgets, remote sensing offers a rapid and inexpensive way to record and analyze data previously unattainable through conventional archaeological methodologies. Two study areas were presented that possess divergent environmental and cultural conditions: Chaco Canyon in New Mexico and Poverty Point in Louisiana.

Use of the thermal infrared regions of both the TMS and TIMS resulted in the successful detection of prehistoric Anasazi roadways and subterranean features in Chaco Canyon that were not visible either with the naked eye from ground level or with simultaneously acquired color infrared photography (Plate 4). Image enhancement techniques using high-pass Gaussian filters were developed in order to accentuate the Chacoan roads on TIMS data imaged at 5 meters. Other filtering techniques were developed that are capable of accentuating linear features. These techniques allow a bias in one direction or in all directions simultaneously. The development of filtering techniques offers unlimited potential in the analysis of prehistoric roadway and canal investigations in other areas of the world. High-pass filtering techniques applied to remotely sensed data can reveal the nature of trade networks and farming practices of ancient cultures in diverse environmental settings. The TIMS also revealed subterranean walls, agricultural fields, and both excavated and unexcavated sites. This unexpected capability was apparently the result of thermal inertia differences between the target features. Preliminary results indicate that remotely sensed thermal infrared data will play a major role in future archaeological research as a result of the ability of TIMS to detect variations in surface temperature within fractions of a degree as well as to determine the emissive properties of various materials.

TMS and TIMS data analysis was also employed at Poverty Point, Louisiana. This massive 400-acre site may date back to 1500 B.C. It is composed of a large central plaza, surrounded by six concentric rings with a large effigy mound lying outside the rings to the west. Preliminary analysis of the digital data revealed anomalies that can be attributed to origins both of historical and prehistoric periods (Plate 5). Areas of prehistoric barrow pits, fill deposits, a ramp entrance, and a corridor extending to an outlying storage area have been verified through archaeological survey and excavation.

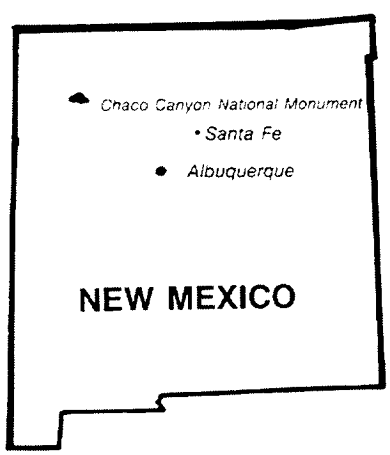
The investigation also addressed the debate concerning four aisles (north, northwest, southeast, and south) that are considered by some scholars to radiate from the central plaza and may be aligned astronomically (Brecher and Haag: 1981). This theory, however, has not been substantiated; the location and parameters of the radiating aisles have not yet been accurately surveyed or recorded. Brecher and Haag maintain that the south corridor is aligned on Canopus, the second brightest star in the sky and the brightest to be seen on the southern horizon. The north corridor, on the other hand, they believe to be aligned on the relatively insignificant star Gamma Draconis, while the northeast and southwest aisles were aligned on the summer solstice sunset and winter solstice sunset, respectively.

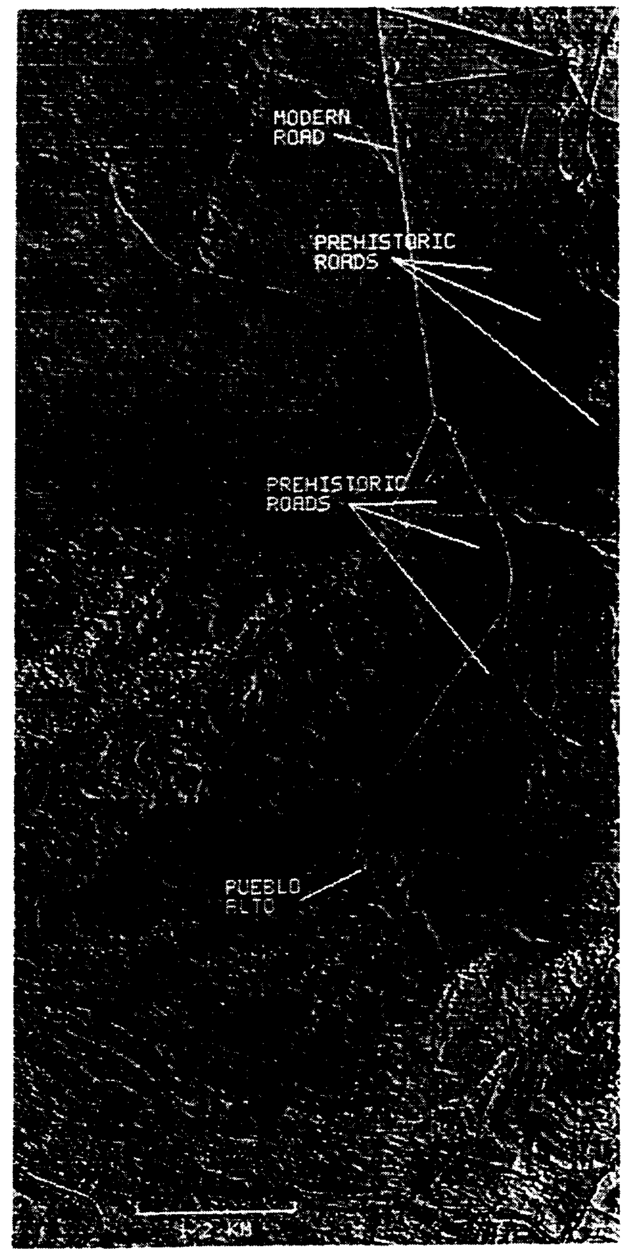
The existence of the north and south aisles remains debatable among archaeologists conducting investigations at Poverty Point. The northwest and southwest aisles, however, are more apparent from ground level and have been recorded by various archeologists (Webb: 1982). As a research approach to verify the existence of these aisles, various high-pass filters were applied to the TIMS data to accentuate linear patterns at the site. While the filtered data did not reveal any indication of aisles to the north and south, they did dramatically highlight the aisles to the northwest and southwest.

CHACO CANYON, NEW MEXICO

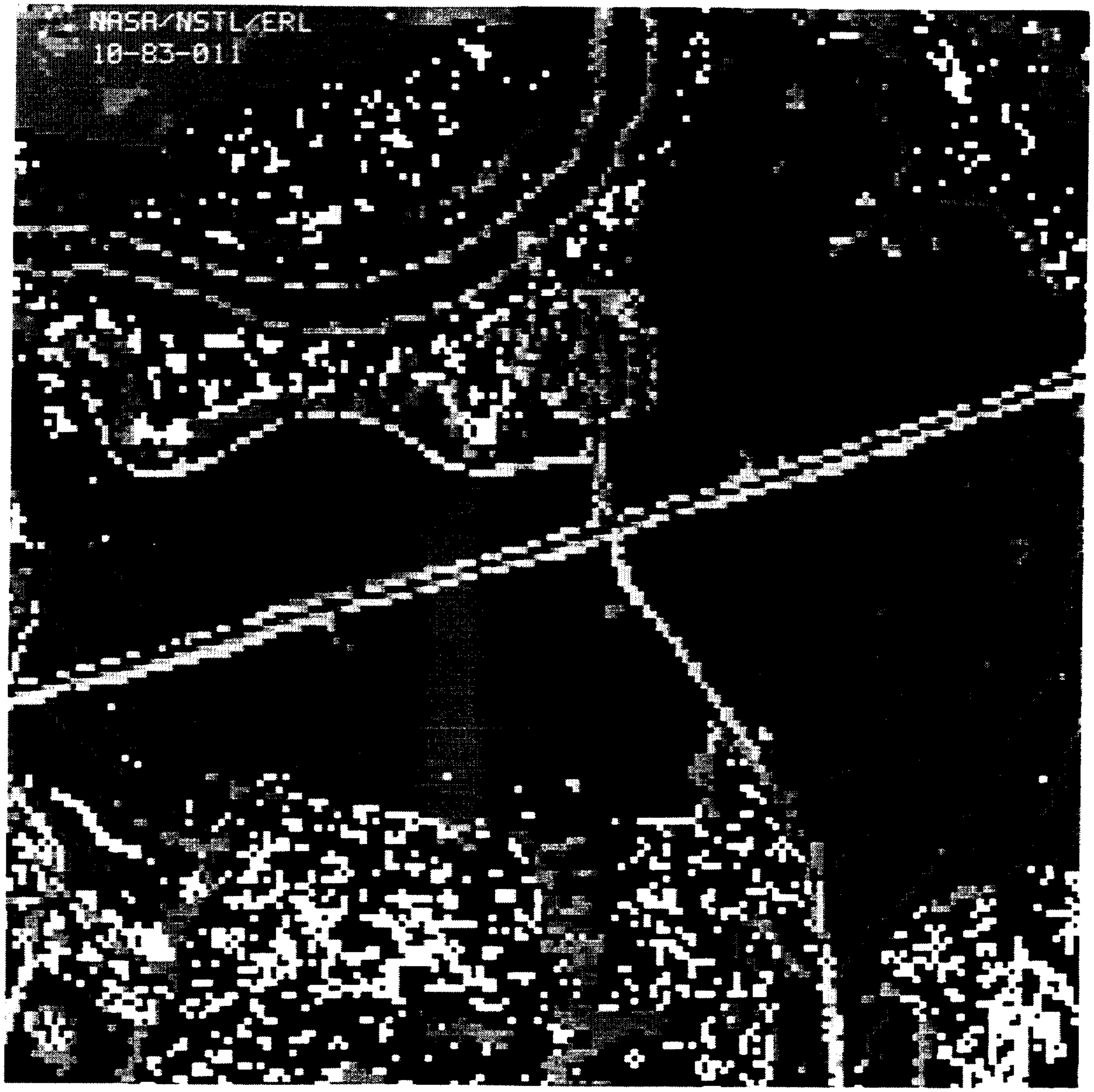
Archaeological Investigation

Pseudocolor composite image from TIMS high-pass filtered data, low-pass filtered data, and raw Channel 3 (9.0–9.4 micrometers) data, assigned to the blue, green, and red colors, respectively. The TIMS data were acquired at 5-meter resolution in August 1982. This image reveals prehistoric roads in Chaco Canyon, New Mexico, which were constructed by the Anasazi culture around 900 A.D. Although these prehistoric roads are not visible from ground level, they demonstrate the ability of high-pass filters to extract information along one axis of an image using digital data.





Prehistoric Road Detection



Classified image using TMS Bands 2, 3, 4, 5, and 7 of Poverty Point, Louisiana. This massive site dates to 1800 B.C. and may represent the oldest civilization in North America. The site is composed of a large central plaza area surrounded by six concentric ridges. Several anomalies were detected in this image which are attributable to both historic and prehistoric cultural remains.

Although it remains uncertain whether or not these detected aisles are aligned to the solstices, the recent research does suggest that the hypothesis regarding stellar alignments for north and south aisles should be viewed with great reservation.

Sever also demonstrated that several features of historical times, such as roads, houses, and cemeteries, which are no longer extant, can be detected in the digital data and can be documented historically to 1840 and with aerial photography to 1927. Even the locations of past excavations by such researchers as Ford, Webb, and Goad can be detected in the data. Finally, additional anomalies within the data were presented that may be attributable to a prehistoric origin, but which can only be verified by future excavation.

GEOLOGY

Dr. Doug Rickman, ERL geologist, directed his attention toward presenting the technical issues an investigator must consider in designing his research approach. Remotely sensed data and flexible software permit one to extract from multichannel spectral data information useful to a specific problem. To be successful, however, the user must have in mind some mechanism or model by which the phenomena of interest may be spectrally observed. This concept is very important since data such as TM can record more than 100^7 levels of spectral information. Sorting through that quantity of data is not possible on a hit-or-miss basis.

In choosing a model one may be able to look directly into the thermal infrared data for the feature of interest (e.g., a buried wall). In other situations, however, one may have to look for indirect indicators, such as the presence of a specific plant species, as a sign of previous habitation. When one has chosen the model, the next step is to determine under what conditions the desired spectral characteristics will be most easily distinguished from the background and sources of possible confusion. Variables can include spatial resolution, spectral bandpasses, and time of year or day.

Successful application of this technology requires an integrated approach. A knowledge of the specialized field of interest, such as Pre-Columbian Maya architecture, is not adequate. In using remotely sensed data one must integrate aspects of ecology, radiation transfer mechanisms, atmospheric physics, computer science, mathematics, and sensor technology -- in addition to one's area of archaeological expertise -- in order to be successful. In this manner it is possible to locate, prioritize, and record archaeological information such as Maya occupational sites beneath dense tropical vegetation, and to direct archaeological research teams to the area to conduct in-depth analyses.

Rickman's research efforts at ERL have made dramatic advances in the area of geological mapping. One of his projects was designed to determine the utility of Thematic Mapper data in the detection and mapping of hydrothermally altered rock, which is a characteristic of specific types of ore systems. The study site was located at Mt. Emmons, Colorado. Emphasis was placed on problems associated with extremely rugged terrain and varying degrees of vegetative cover. Using various analytical techniques, a number of images were generated from the same basic data set, each fulfilling separate needs. For example, by using appropriate ratioing techniques and basing his investigation on a prior knowledge of reflectance spectra, Rickman detected zones of anomalous hydroxl and ferric iron concentrations that were free of vegetation. Another analysis technique resulted in a principal component composite that emphasized zones that were spatially correlated with known areas of mineralization. Finally, a vegetation map was developed from supervised statistics on ratios, and it functioned both as a scientific tool and as a baseline environmental assessment (Plate 6). In addition, the remotely sensed image was produced at a fraction of the cost of the vegetation maps. Through statistical analysis of the data, Rickman has revealed some apparent relationship between vegetation density and several digital ratios. If it can be quantified, the relationship may be used to develop an ability to infer composition of the rock and soil beneath the vegetation.

SMALL FEATURE EXTRACTION: SURFACE MINES

Dale Quattrochi, ERL geographer, presented a data enhancement technique known as principal components analysis (PCA). This technique has been employed at ERL to discriminate surface coal mines as discrete land cover features. Because of their small size, irregular shape, and heterogeneous land cover composition, surface mines have in the past been extremely difficult to identify as unique features from satellite-acquired data. With this methodology, however, surface mines have been discriminated using digital analysis of both Landsat Multispectral Scanner and Thematic Mapper Simulator data.

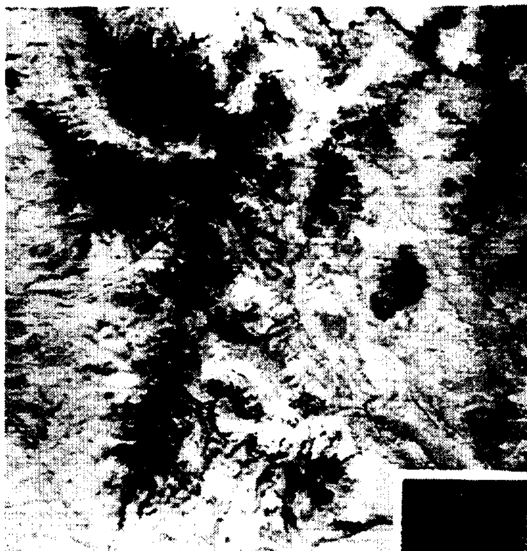
In a study conducted utilizing TMS data collected over a portion of the Eastern Kentucky Coal Field in February 1981, PCA was applied to the data to enhance surface mines as discrete land cover features. Moreover, the visual enhancement of the data has in turn led to a successful digital classification (i.e., land cover typology) of surface mines and related land covers from the TMS data. The significance of using PCA-enhanced data over original or "raw" data for the detection of surface mines becomes significant when these data are viewed on an image display device. The first principal component (PC1), referred to as "brightness" in the past, enhances surfaces that have high or intense spectral responses. Hence, surface mines with their abundance of bare soil and disturbed earth have a bright reflectance in PC1. In contrast to

PC1, the second principal component (PC2) has been called "greenness" because it enhances the reponses of vegetation in the data. For areas that have been surface mined, it is the <u>absence</u> of green vegetation that makes PC2 important to the overall scheme of detecting these areas. Because surface mines have a much darker response in PC2 (i.e., lack of vegetation produces a dark response), these areas contrast sharply with the heavily forested land in eastern Kentucky that surrounds the surface mines.

Experimentation at ERL has shown that although both PC1 and PC2 are important for the visual detection of surface mines, a <u>ratio</u> of the two (i.e., PC1 divided by PC2) further enhances the visual contrasts apparent between mined and non-mined areas. Once a PC ratio has been developed, a range of digital values that correspond <u>only</u> to surface mines and related land covers is defined using visual interpretation of ancillary information. For example, aerial photography can be used to assist in the identification of specific digital spectral values inherent only to surface-mined areas. After a unique spectral value range has been defined for these areas, pixels with spectral values within this predetermined range are subjected to digital classification. All other nonsurface-mined areas are eliminated from the classification. The result of this procedure is a thematic "mask" of surface mines only, with other land covers suppressed or masked out.

Principal Component Analysis could be employed in archaeological research to extract archaeological features from the data and perhaps used to categorize these features. PCA was successfully used at Poverty Point as a resource management tool to locate the main flow pattern in a forested swamp that threatened to erode and damage the site.

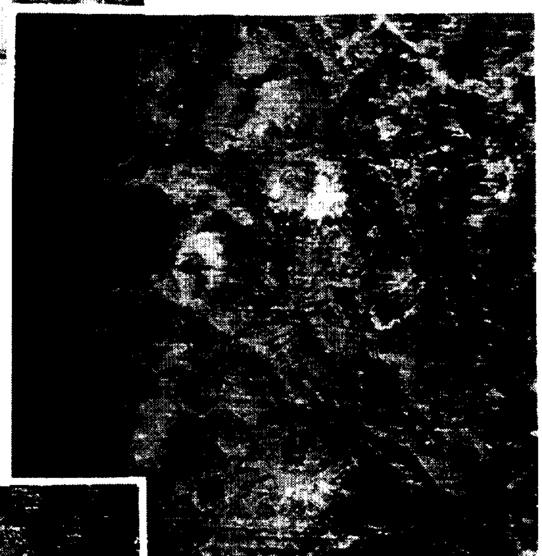
APPLIED RESEARCH AND DATA ANALYSIS
Geological Mapping



(A) RATIO COMPOSITE

TM Ratio	*Color*
5/6	*Blue*
4/2	*Green*
5/1	*Red*

Dark Magenta Indicates Mineralization



(B) PRINCIPAL COMPONENTS

Principal Components	*Color*
6	*Blue*
4	*Green*
3	*Red*

Yellow Is Associated with Rock Alteration

(C) VEGETATION CLASSIFICATION

Class	*Color*
Trees	*Greens*
Meadows	*Blues*
Rocks	*Reds/oranges*
Rock/Vegetation	*Black*

UTILITY OF THEMATIC MAPPER

(D) DECORRELATION

Channel	*Color*
6	*Blue*
5	*Green*
4	*Red*

(E) MERGED SPECTRAL AND TOPO DATA

Item	*Color*
TMS Channel 5	*Gray*
Streams	*Blue*
UTM Grid	*Yellow*
7.5' Boundary	*White*
Contours	*Brown*

(F) RATIO COMPOSITE PERSPECTIVE

Perspective View of Ratio Composite (A) Viewed Toward the Northwest

DATA FOR MINERAL EXPLORATION

MT. ST. HELENS

Gene Zetka presented the results of an investigation that was directed at quantifying and categorizing the physical damage caused by the volcanic eruption of Mt. St. Helens. Located in southeast Washington State, Mt. St. Helens erupted at 8:32 a.m. on May 18, 1980. The north-facing slope gave way in a giant avalanche of rock, mud, and ice, thereby allowing the tremendous pressures within the mountain to escape in a lateral as opposed to vertical direction, thus causing greater surface damage. The lateral blast stream of steam and gases, moving at 160-320 km/hr (100-200 mph) with temperatures at 500-1500^{o}C, destroyed or damaged at least 60,000 hectares (230 sq mi) of forest. Within a 10-km (6.2-mi) radius of the northern flank, the area was completely scoured of all vegetation and covered with up to 2 meters of ash. Trees were blown down and stripped of vegetation up to a distance of 10-15 km (6.2-9.3 mi). Blast effects were evident as far as 26 km (16.1 mi) away from the crater. Sixty-one people were listed as dead or missing.

Two sets of Landsat MSS data were processed: one was the pre-eruption MSS scene dated September 11, 1979, and the other was the post-eruption scene of September 24, 1980.

Initially, image enhancement techniques were employed to reconstruct the digital data into a color display that approximated the response of color infrared aerophotographic films. In this manner it was possible to compare the pre-eruption and post-eruption conditions of the vegetation, soil, clear water, etc., surrounding Mt. St. Helens. Next an MSS classification was produced to determine if a portion of the blast damage could be isolated and categorized. Using signature development software and computer-assisted, pattern-recognition processes, the digital data were used to produce an image of the land cover classification (Plate 7).

Bare soil in the area where the devastation was absolute (Caldera Surface) had unique signature characteristics in the MSS data. The Mud-Debris Flow area, while similar to the caldera zone, was spectrally distinct to a degree that this volcanic material flow pattern could be traced down portions of the north and south Toutle River Valleys. The bulk of the blast zone was categorized as Blowdown. This area consisted of mature trees that were devoid of vegetation, mostly strewn in disarray, and to some extent covered with ash. It is noteworthy that at the extremes of the blast-effects zone there was a fringe zone with a distinct signature (Damaged Trees). This was the area where the timber was known to have been slightly damaged - a moderate amount of heat-induced discoloration of the green vegetation. Four months after the eruption, the "singed fringe" retained a distinct spectral character. There was sufficient ash-related turbidity in Swift Reservoir for it to be classified separately. Finally, the altered configuration and floating debris in Spirit Lake could be determined.

Since the land surface cover classification was performed on the MSS data in its digital form, it is possible to quantify the areal extent of each land-cover class.

Using special 3-D software at the ERL, the National Cartographic Information Center (NCIC) elevation information in the immediate vicinity of the Mt. St. Helens peak was prepared in a perspective presentation. Plate 7 shows the "before" condition where the 2,950m (9,677-ft) peak is viewed from a northerly position (-10^{0}) and at a 45^{0} tilt. The color image has a 3-to-1 elevation enhancement applied (i.e., the Z axis is three times the X and Y axis). As a coarse scale indicator, the red colored elevation zone in the image is approximately 610m (2,000 ft) high.

MT. ST. HELENS

Before

After

Two sets of Landsat MSS data of Mt. St. Helens processed at ERL. The above image is the pre-eruption MSS scene dated September 11, 1979. The image below is the post-eruption scene of September 24, 1980, and shows the effects of the physical damage caused by the May 18, 1980, eruption.

Before

After

Oblique perspectives of the Mt. St. Helens peak using special 3-D software at ERL and National Cartographic Information Center (NCIC) elevation data.

Land cover classification of the post-eruption conditions of Mt. St. Helens. This Landsat MSS classification was produced using signature development software and computer-assisted, pattern-recognition processes.

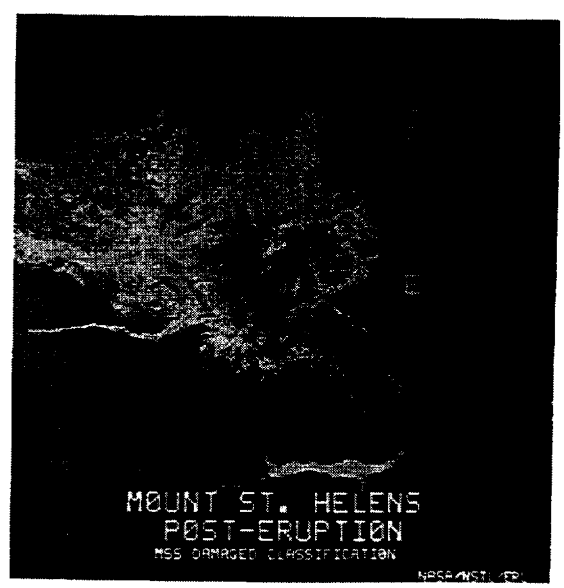


Plate 7 also displays a 3-D rendition of the mountain's "after" state. Again, by viewing the mountain in a southerly direction, the magnitude of the eruption can be better appreciated. The uppermost (gold colored) peak is missing, signifying the net loss of 400m (1,300 ft) of elevation in the total eruption. The width of the crater is approximately 1.9 km (1.2 mi), while the crater depth from the south rim is 660m (2165 ft) (exaggerated by the 3:1 aspect ratio). This topographic void is understandable, based on the reported volcanic ejecta volume of 3 km^3.

Zetka demonstrated that the two types of data can be brought together in a computerized data base, and manipulated as a complementary set to explain possible cause and effect relationships in the natural disaster. For example, with the superposition of the MSS damage classification onto the elevation data, one could gain insight into the effects of local topography on the survival of the vegetation singe fringe. When displayed in a 3-D perspective, the classification and topography data would be a powerful tool for post-event analysis or as a visual manifestation of computer-assisted predictive modeling processes.

OLYMPIC NATIONAL PARK: DATA BASE ANALYSIS

Data base construction was explained by Dr. Bill Cibula, ERL botanist, using Olympic National Park as an example. An unsupervised computer classification of vegetation/land cover of the park and surrounding environs was initially carried out using four bands of Landsat MSS data. Nine generalized vegetation/land cover classes were derived with an overall accuracy of 91.7%. Field investigation revealed, however, that there was considerable spectral overlap in the classification. In an attempt to refine the level of classification, a geographic information system (GIS) approach was employed in which topographic and climatic data were registered with the Landsat MSS data.

NCIC digital terrain data were processed to produce elevation, slope, and aspect, and seven geographic regions were defined to account for the variation in rainfall and climate in the area. For instance, on the west side of the park, which included the Hoh River Valley, the area receives more than 240 inches of rainfall per year. Areas on the northeastern side receive much less precipitation, and in some areas as little as 20 inches per year.

These parameters - elevation, aspect, slope, and climatic regions - were input into the Olympic data base and stored as separate channels of information along with the nine-category land cover classification. Using the capability of the programmable calculator (PCAL) in ELAS, elevation and aspect were compared against the nine land cover types as they related within the defined geographic regions to produce a classification of 21 land cover types; the additional classes represented species separations of some of the major forest communities which occur within Olympic (Plate 8).

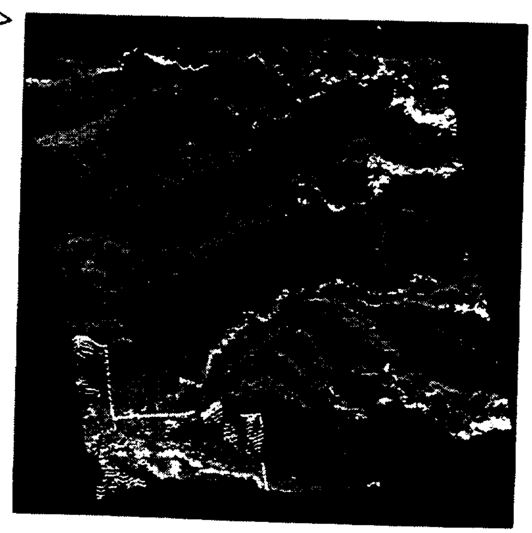
Cibula explained that the same data base could be used in a cost effective manner to produce different types of information. To illustrate his point, Cibula used fire-modeling as an example. Olympic National Park, with almost one million acres within the Pacific forest system, provided an appropriate study area. In 1978, a fire was discovered on the south slopes of the upper Hoh Valley. A decision was made to attempt fire control, resulting in a cost of $900,000. Since the fire eventually burned itself out because of natural terrain and vegetation features, there was little need for a fire-control effort. Recent studies by the National Park Service have shown that an assessment of fire hazard can be made on the basis of elevation, aspect, steepness

OLYMPIC NATIONAL PARK
Data Base Application

Landsat surface cover classes were integrated with NCIC elevation and aspect to produce a surface cover classification. Within the 21 classes developed, 4 classes delineate different species compositions of conifer forest communities and 7 represent hardwood and hardwood/conifer mixtures. For instance, the five conifer forest communities include:

- *Subalpine Forest and Silver Fir (reddish purple)*
- *Western Hemlock, Douglas Fir, and Silver Fir (greenish blue)*
- *Western Hemlock and Douglas Fir (dark green)*
- *Lowland Western Hemlock and Sitka Spruce (purplish pink)*
- *Coastal Hemlock and Cedar (dark blue)*

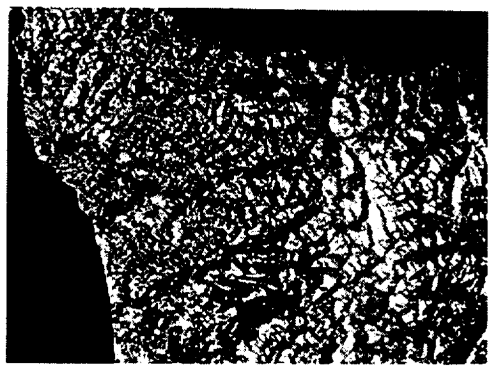
Enhanced Surface Cover Classification



ELAS topographic processing procedures have been developed to display land cover classifications in a three-dimensional perspective, as shown here. This capability allows a given study area to be viewed from any angle or direction. This particular color product shows the Hoh Valley, looking northwest. The color mapping of the classification data plane has been placed on the perspective plot to relate the data elements to the topographic elevation data with a rotation of 10 degrees and a tilt angle of 45 degrees.

ELAS software has been developed to produce elevation levels, slope, and aspect from NCIC data. In this example, two aspects are presented which show slopes facing north and west, respectively. Aspect directions can be derived from the ELAS processing capability to within 1.4 degrees accuracy.

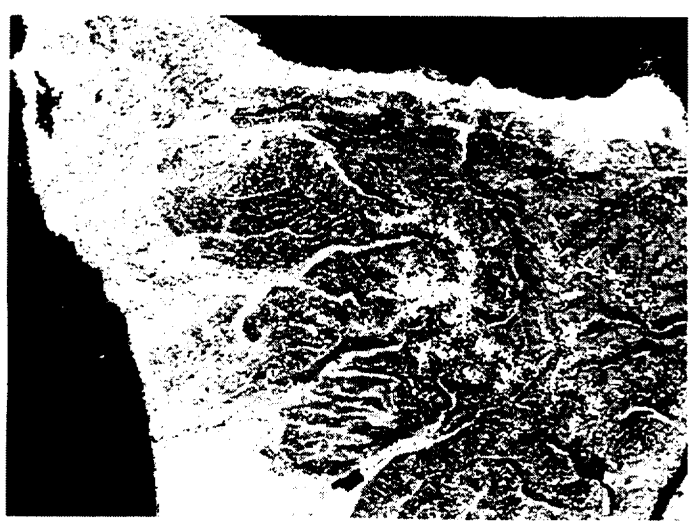
North Aspect



West Aspect

Fire Hazard and Behavior Map

One database application was developed to address the analysis of fire behavior within the park.



Areas of high fire risk (mapped as shades of red and green) occur primarily on south, southeast, and southwest facing slopes in forest communities with Douglas Fir or Silver Fir as a major constituent. Intermediate to low fire risk areas (mapped as shades of blue and brown) occur on north, northeast, and northwest facing slopes, while the large areas of gray at lower elevations represent grass, hardwoods, and cropland with very low potential for fire. The areas of no fire risk, such as water, inert materials, and glaciers, are color-coded blue, black, and white, respectively.

of slope, and land cover type present at the location of a fire's outbreak. Using the 21-class land cover classification for Olympic, a model was constructed to this application. Elevation, aspect, and steepness of slope were integrated with the land cover information derived from Landsat in much the same manner as they were used for species separation. A final map product was made that reflected areas of high fire risk, intermediate risk, and low or no risk.

Data base technology could contribute significantly to archaeological research by analyzing environmental and cultural parameters. The relationships between archaeological sites and their environs (e.g., surface cover, topography, soils, and hydrology) could be better understood through the interactive analysis of this information. This technology could also be used to model and predict ways human societies may have made use of geographical regions in the recent and remote past. In addition, the development of accurate models capable of predicting the locations of archaeological sites could be employed by the archaeologist to prioritize areas for survey and excavation and thus accelerate the understanding of prehistoric man/environment relationships.

GEOBOTANY

Dr. Cibula said the overall objective of the geobotanical research program is to develop and evaluate practical techniques for deriving geobotanical information from remotely sensed data acquired by air- and space-borne systems. The primary emphasis is on ore-bearing terrains in areas that are moderately to heavily vegetated. Specifically, emphasis is placed on differences in the vegetative cover that appear to relate to the surficial geology. These variations can be either differing vegetation types resulting from geological structure or perhaps subtle differences in canopy spectral reflectance caused by varying mineralization in the soil.

Cibula demonstrated how one investigation used MSS data to locate subsurface phenomena through the analysis of the surface vegetation. In this application, four seasonal sets of Landsat data over the Sam Houston National Forest in east Texas were analyzed by using computer programs that develop homogeneous spectral classes from multivariate data. One Landsat frame was acquired in the early summer of a year that experienced a protracted drought. The results of analysis revealed that a spectral class within the upland pine forest correlated well with known deposits of ironstone gravel. In this manner, remotely sensed data were used to map ironstone gravel deposits beneath heavily vegetated terrain. What is more, it was established that the pine forest spectral class closely correlated with stressed regions within the forest type as a result of the subsurface geology. As a result of this investigation, it was determined that subsurface gravel produced a soil that had less field capacity for water retention, causing early appearance of water stress in the surface vegetation.

Another geobotanical application centered around the Haile Gold Mine near Kershaw, South Carolina. Four major lithologic divisions were separated in the study area image: Cretaceous sediments (unconsolidated quartz sand), areas of felsic metavolcanic rocks, coarse-grained adamellite of the Carboniferous Pageland pluton, and medium-grained foliated and metamorphosed metatonalite. In summary, the underlying geological materials appear to have a significant effect on the incumbent vegetation. This investigation is currently being expanded to the northern portion of the study area, where there is much less disturbance to the natural vegetation as a result of human activity. Field work in the future will attempt to quantify the geobotanical relationships manifested in the data.

CORRIDOR ANALYSIS

David Brannon, ERL ecologist, presented his research on corridor analysis techniques which are designed to determine optimum routes for moving heavy equipment from one point to another. Based on data developed for Baldwin County, Alabama, a model was developed that was composed of five information planes geographically referenced to a 50-meter grid cell size. The information planes included: (1) Landsat MSS-derived land cover, (2) U.S. Soil Conservation Service detailed soils survey, (3) National Cartographic Information Center topographic data, (4) digitized primary and secondary roadways, and (5) digitized urban boundaries. Variables within each information plane were ranked according to their ability to support traffic.

The original data comprising each data plane were very detailed and contained more information than was required for the application. In order to incorporate these data into the weighted simulation model, the variables within each data plane were aggregated into relevant categories based on hypothetical criteria for determining trafficability. From the NCIC digital terrain data, elevation is the original data plane variable from which aspect and slope can be derived. For the application, percent of slope was computed as a limiting factor for trafficability. The importance of transportation networks and urban centers was a function of distance, which was computed using an algorithm that determines the Euclidian distance between specified units.

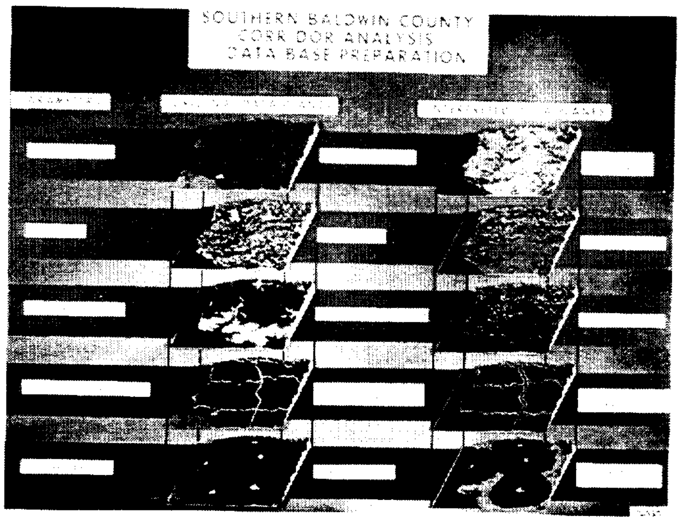
In weighted simulation modeling, each cell representing the categories within each data plane was assigned a ranking value (X-value) within a range from 0 to 10, with 0 representing the best condition and 10 representing the worst. The conditions placed on corridor selection in this exercise were assigned arbitrarily. For example, within the land cover data plane, 58 spectral classes were combined to form nine categories. These were ranked in terms of trafficability, with those categories offering the least resistance to corridor development (cultivated lands, pasture, etc.) assigned the lower values. In each case within the remaining data planes, the lower ranking values were assigned to the areas most conducive to corridor development (Plate 9).

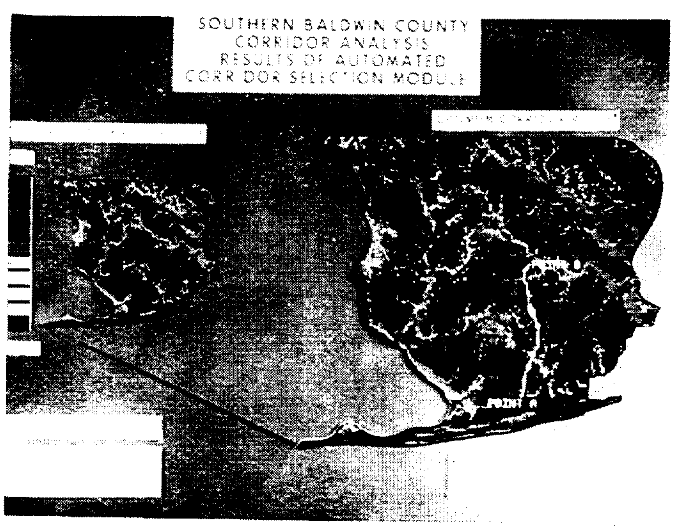
A significance value (N-weight) was then assigned to each data plane. The N-weight was multiplied by the X-value for each cell (expressed as $x_i n_j$ = acceptability value) to determine the relative trafficability value within each data plane. the data planes were registered and the corresponding cell acceptability values within each data plane were then totaled to determine a range of trafficability.

For the actual corridor selection, given Point A as the departure point and Point B as the target, the algorithm defines a minimum distance (path of least resistance) from Point A to Point B. All data planes had different weights of importance assigned. Only when the urban exclusion zone was assigned a 30% weight did the corridor selection algorithm avoid the urban center.

The purpose of this hypothetical example was to test weighted simulation modeling within the ELAS software package. The significance lies in the flexibility of ELAS: (1) to handle data from different sources available at different scales, (2) to standardize by geographically referencing each data set to the UTM coordinate system, and (3) to perform an interactive analysis of all data planes. No restriction is placed on the number or type of data planes that can be used.

As decision-makers place increasing reliance on automated approaches for synthesizing, weighted simulation modeling represents a valuable tool for





A digital data base was constructed in Baldwin County, Alabama, from satellite remote sensing data and other geobased information including: (1) Landsat MSS-derived land cover, (2) U.S. Soil Conservation Service detailed soils survey, (3) National Cartographic Information Center (NCIC) topographic data, (4) digitized primary and secondary roadways, and (5) digitized urban boundaries. This data base was used as an input into a weighted model which assigned trafficability values to each 50-meter grid cell in the study area. The ten levels of the trafficability were then used to compute the most accessible corridor.

developing a range of options for consideration. Corridor analysis may offer a valuable tool for the archaeologist by enabling him to identify ancient travel routes. It may also be used both in predictive modeling and location analysis.

DATA BASE DEVELOPMENT FOR SOIL EROSION MODELING

Dr. Ken Langran, NASA geographer, discussed soil erosion modeling. The need to estimate soil erosion losses in conjunction with non-point pollution control and future soil productivity has become essential in conservation planning and agriculture decision making. One technique that was developed to monitor soil erosion is combining remotely sensed data with ancillary data (topographic, climatic, soil type). The Universal Soil Loss Equation (USLE) was used to produce a soils geographic information system. This technique is applicable to a number of research issues in the physical and social sciences, including those identified in archaeology.

Langran explained that the USLE was designed to predict long-term soil losses from sheet and rill erosion for given field slopes under specified land use and management practices. Included in the model's equation are: upland soil erodibility (K), slope length (L), slope steepness (S), cropping and management techniques (C), and supporting conservation practices (P). The predicted soil loss per unit of area (A) is computed by multiplying values of the above components: $A = R * K * L * S * C * P$. In building a soils geographic information system, the spatial distribution of data values (or cells) for each component is identified and registered. A computer program in the ELAS software system multiplies the combined application component data cells and produces a spatially distributed soil loss.

IV. DISCUSSION

GENERAL

Discussions on the second day of the conference were concentrated on issues of policy, as represented by Questions 1-3 in the Agenda (Appendix B). That is, the participants concerned themselves at length with developing a consensus on which areas of archaeological research, and what kinds of archaeological problems, should be the focus of the discipline in the immediate future of remote sensing applications. In the course of the discussion a number of related concerns -- practical problems, logistical implications of action that might be taken at the Conference, and other concerns for the future -- were also taken up. The discussions are summarized and the resolutions adopted are outlined in the following subsections under the headings POLICY, RELATED CONCERNS, and ACTIONS.

POLICY

The development of a policy, it was clear to all, was particularly constrained by the rarity of previous archaeological applications. The presentations of the first day (see Section III) were highly informative, and a number of potentially valuable approaches to archaeological problems could be designed on analogy, but their actual effectiveness could only be determined empirically. Robert Adams early in the discussion focused our attention on how limited our knowledge is by posing the question: What can we learn (in archaeological terms) from different-sized pixels? The point, only as one example, is that we do not yet even know if the greater resolution possible by aircraft-borne sensors will provide additional or better data than sensors operating from space. There is, therefore, an urgent need to find out just what can be learned from the different kinds of data that can be gathered. He suggested that a site or region about which a considerable amount is already known from other sources should be selected and the new technology tested there. The Valley of Mexico was immediately suggested by some of the participants as an appropriate test region; other suggestions were both site-specific (e.g., Colonial Williamsburg) and ecologically disparate (e.g., arid lands or tropical forests).

James Muhly and others emphasized that a great deal of information is already available as a result of remote sensing and urged the wisdom of making use of those data in our first applications. Bert Salwen pointed out that since much of that information is ecological, we might focus first on projects in progress, or in the planning stage, that are concerned with ancient ecology.

A number of other suggestions were made concerning the type of applications of remote sensing that should have some priority, including resource management and developing the technology's potential for predictive modeling (George Frison); the location of quarry sites in the United States (Lawrence Banks); the study of land forms and ancient shorelines (R. Adams); and site location and mapping, along with the testing of models based on predictions resulting from computer analysis of the remote sensing data (C. R. McGimsey). J. W. Myers commented on the recent efforts by David Wilson in England to detect regional patterns of settlement through aerial photography. He suggested that the new technology provides even more useful images for such an exercise, and that it might be possible to identify cultural groups by regional patterns, which could in turn lead to archaeological expectations (i.e., predictive modeling) in other regions.

Glyn Isaac, responding to Wiseman's suggestion at the opening of the discussion that we might identify major archaeological problems that remote sensing could help to resolve, suggested three areas of research: human origins, the rise of civilization, and the emergence of agricultural systems. Carole Crumley urged that we keep in mind that the methodological concerns should come after, and to some extent be prompted by, anthropological reasons for the specific research.

Cynthia Irwin-Williams recapitulated the areas of archaeological research where there seemed to be substantial agreement that remote sensing technology could play an important role: site location and point resource, the range of palaeo-environmental resources, ecology, mapping, hypothesis formulation (predictive modeling) and testing, cultural resource management, and general ethnological investigations. Sever pointed out that our topics fell into two basic areas: 1) environmental analysis (including regional analysis and detection of natural resources), and 2) predictive modeling. Banks and Frison, though in agreement with the areas delimited, emphasized that priority within those areas, whether in the United States or elsewhere, should be given to cultural resource management, especially to endangered resources.

George Rapp and Richard MacNeish suggested that the overall policy statement might be one reflecting also the basic aims of archaeology, with an emphasis on the relationship of humans and earth, and the nonrenewable nature of cultural resources. The policy thus conceived, the participants agreed, could not only serve to guide the Committee, but could also be communicated to NASA, to the archaeological discipline, and to the public at large. Responsibility for the precise formulation of the statement, based on the concept as approved, was entrusted to the authors of this report. The statement follows.

The basic, general aim of archaeology is the study of humans and human societies of earlier times in their environmental contexts, including their interrelationships and evolution. Archaeologists thus place a fundamental emphasis on the relationship between humans and earth because the changes in both since the appearance of the earliest humans have involved interactive processes that inevitably affected both: study of environmental context is an inseparable part of the study of human society. And since the traces of earlier humans and of earlier times are preserved in and on the earth, an understanding of earth and environmental processes is required even to detect them, or to recover them, before we can interpret them. What is more, these remnants of the past constitute a nonrenewable cultural resource that is in the vital interest of all modern and future human societies to protect and study, since those remnants constitute the most reliable record of the human past. The most immediate applications of remote sensing technology and related computer-assisted analysis, therefore, should properly be in the analysis of the environments of human societies and their interrelationships. Such analyses should take advantage of the new technology's potential for helping to generate and test models both of human behavior and environmental change. Finally, projects in the immediate future should be developed and especially encouraged that bring these applications to bear on endangered resources, whether in the United States or elsewhere.

RELATED CONCERNS

A number of other concerns related to the application of remote sensing technology in archaeology were touched upon in the course of the discussion of March 2, and are summarized here.

A topic that emerged early in the discussion and to which the conferees frequently returned was the concern for proper training in remote sensing for archaeologists. NASA, or more specifically ERL, could conceivably sponsor a training program, but, as Patricia Conner pointed out, was better suited to dealing with a few rather than many people at a time. The Intergovernmental

Personnel Act, for example, makes possible an exchange of personnel that could facilitate a modest training program. The exchange could be State to State, university to Federal, or other, and could help to support institutions that are involved in joint projects. Training in this way could be provided on a one-on-one basis or for larger groups for three to six months. Sever commented, in response to a question by Isaac, that a basic "course" on remote sensing would require about three months if the participant knew nothing about the subject; a much shorter time would be required if the participant started with some knowledge.

Training programs and the development of some institutional sponsorship were viewed by the conferees as major concerns, since there is virtually none of either in the United States, despite its acknowledged leadership in the general applications of remote sensing. In Europe, for example, at the First International Conference on Remote Sensing and Thematic Cartography in Archaeology in 1983, announcement was made of the plan to establish in Strasbourg, France, a European Remote Sensing Center, where a training program for archaeological research would also be instituted. A possible national institute in the United States was discussed, as well as roles that other governmental agencies might play. The conferees felt, however, that, in addition to whatever training NASA might be able to provide directly, the training programs most likely to be developed would be those that would emerge as concomitant developments of research projects that employ remote sensing and are based at educational institutions.

Funding problems for the programs would also be alleviated by such an approach. As John Yellen pointed out, NSF cannot provide funding for a training program for students, but could provide funds for training as part of a research project. Eugene Sterud noted that the same constraints existed at

NEH. Carole Crumley commented that the necessary training programs could be made parts of centers at various universities. As an editorial comment here, we note that remote sensing has already achieved some standing in university curricula and is likely (in the view of the authors) to achieve an even broader curricular base, cutting across a number of departmental lines, because of its constantly increasing use in geography, geology, meteorology, the biological sciences, and now archaeology and other disciplines.

Costs and cost-effectiveness were raised as issues not only in connection with training programs, but also general research. Rapp pointed out that it would not be possible to become specific about the feasibility of certain types of research until information on the costs of remote sensing equipment, services, and data are fully available. The problem is especially acute with sensors, such as the Thermal Infrared Multispectral Scanner, that are carried by aircraft. As Sever pointed out with regard to the latter, 90% of the cost goes for fuel for the aircraft; the remaining 10% covers the crew and the scanner. What is more, the plane can stay in the air only four hours; as a result, it has been used so far only in the Western Hemisphere, primarily in the continental United States. Aircraft-borne sensors, however, can be used abroad; but careful planning (in addition to funds!) is required. The sensors, for example, might be transported to the country where the project is to be carried out and mounted on a plane there. Or the aircraft already adapted for the sensors might, go to Europe in a series of short hops across the North Atlantic. In the latter case the economical approach would be for several projects to fund jointly the trans-Atlantic crossings. The Committee on Remote Sensing in Archaeology might be able to provide the necessary coordination of schedules.

The importance of determining what other agencies can contribute was also repeatedly stressed. T. W. Jacobsen raised the question of what the U.S. Navy's research division has developed in remote sensing that might offer aid for underwater archaeological research. ERL had no specific information on that topic, but various researchers were aware that there had been recent developments in underwater detection devices. Communication with other agencies, such as the National Park Service and Corps of Engineers, should result in a better understanding at least of new developments in remote sensing, and might help improve the feasibility of projects still in the planning stage.

The need for improved communication within the discipline of archaeology about remote sensing was addressed in a variety of ways. Rapp suggested that a review article on the state of the technology in an archaeological journal would be useful. Wiseman responded that he was planning a short work on that topic as an editorial commentary for the Journal of Field Archaeology, which would also include a summary of the Conference. Patty Jo Watson, as Editor of American Antiquity, indicated that a report of the Conference would also appear in that journal. The conferees urged that information about the Conference be made available also to all the other principal archaeological journals and to the newsletters of the several archaeological organizations. They also discussed the form that the full report on the Conference should take. (The suggestions on form and content that were approved at the Conference have all been followed in the preparation of this report.)

A matter related to communication, but more fundamentally involved in the likely immediate application of remote sensing in archaeology, was raised by Salwen as "a clear and present danger." He expressed the concern that some persons, especially officials at agencies responsible for approving environmental impact studies, might place excessive reliance on predictive modeling programs for site location based only on data from remote sensing, and unjustifiably conclude that, if no sites are indicated by those data in a particular region, then no sites in fact exist. The conferees agreed that "ground truth" should include not only direct observation aimed at confirming or rejecting a proposed spectral identification of, say, an archaeological site or natural resource, but also some amount of ground search in areas where the computer images do not indicate by spectral signature the kind of site or natural resource that is an object of the research. That is, archaeologists must continue to expect the unexpected and to search, or at least to sample, also places where they do not expect to find sites or resources.

ACTION

In addition to developing a policy that might be used as an initial guide for the Committee on Remote Sensing in Archaeology and for the other purposes set out in the subsection "POLICY", the Conference adopted the following resolutions:

1. That all actions to date by the Committee on Remote Sensing in Archaeology stand approved by the Conference, including the recent addition to the Committee of James Judge and George Rapp. The Conference also recommended that Thomas Sever be added to the Committee.

2. That the Committee continue its official contact with NASA to assure that agency of the interest of archaeologists in remote sensing, and to encourage NASA to note the policy approved at the Conference with regard to archaeological projects.

3. That the Committee adopt as guidelines for action the policy, resolutions, and sentiments of the Conference.

4. That the participants at the Conference, at the invitation of the Committee, become the Advisory Council on Remote Sensing in Archaeology to provide in the future continued guidance to the Committee and to serve as a broader liaison with the discipline.

5. That ERL be invited to consider what areas of cooperative activity, whether in research or training programs, we might most usefully engage in at this time, and that it also consider forming now an archaeological unit.

6. That the results of the Conference be disseminated broadly through professional journals and newsletters, and that a detailed report on the Conference be prepared for publication by Sever and Wiseman.

7. (By acclamation) that the sincere gratitude and deep appreciation of the participants be conveyed to ERL, its director, scientists, and support staff for hosting the Conference. The Conference participants also expressed by applause their special appreciation for the tireless efforts of Thomas Sever in introducing archaeologists to remote sensing technology.

V. CONCLUDING REMARKS

The two projects cited in Section I that received funds from NASA for the remote sensing aspects of their research have progressed considerably since the time of the Conference. Payson Sheets completed a spring field season in Costa Rica, and Sever was present for part of that time. One of NASA's Learjets, carrying remote sensors, flew over the project area (Volcan Arenal) and recorded data using Lidar, a newly developed device that combines radar and a laser profiling beam, which was expected to penetrate the tropical jungle canopy more effectively than other remote sensors. SIR-B data were expected both for the Volcan Arenal region and for Isaac's project area in Kenya. A malfunction in the positioning device for the radar antenna on the Space Shuttle flown in October 1984, however, resulted in the gathering of less radar data than planned. At the time of this publication, it was known that SIR-B data would be available for East Africa but not Costa Rica. On the other hand, other high-quality, remotely sensed data, as already noted, were either already available or were newly gathered. In addition, NASA was scheduling a SIR mission in May 1985 that would concentrate on tropical areas such as Costa Rica.

Among other recent developments, we may note that the Departments of Archaeology, Geography, and Geology at Boston University have received administrative approval both at the College and the University level to proceed with the establishing of a Center for Remote Sensing. Two archaeological projects that would utilize the new Center facilities, which are expected to be in operation in 1985 following faculty and final administrative approval, are currently being planned for northern Portugal and northwestern Greece.

Carole Crumley recently brought to our attention that Thomas Isenhour, formerly Chairman of Chemistry at the University of North Carolina and now Dean of Research at Utah State University, is working on another type of sensor that may have implications for archaeological research. Wiseman subsequently spoke with Isenhour and learned that the sensor, called an Interferometer, makes use of infrared spectroscopy. Isenhour, who has an NSF grant for his research, said the sensor, which would be mounted on an aircraft when it is eventually built, may be able to detect carbonates up to several feet below ground. How soon the sensor can be tested has not yet been determined.

The progress of the first two projects funded by NASA, other developments such as those just cited, and, above all, the highly successful Conference at ERL last March have convinced the authors that the high promise that remote sensing holds for archaeology will receive some substantial demonstration over the next two to four years. It will be one of the tasks of the Committee on Remote Sensing in Archaeology, with the aid of the Advisory Council established in March 1984, to help keep the discipline informed both on developments and results.

APPENDICES

Appendix A

List of Participants
Conference on Remote Sensing in Archaeology

Robert McC. Adams, Provost
University of Chicago
5801 S. Ellis Avenue
Chicago, Illinois 60637
(312) 962-8810

William Hampton Adams
Office of Archeological Excavation
and Conservation
Colonial Williamsburg Foundation
P. O. Box C
Williamsburg, VA 23187
(804) 229-1000 X2097

Larry Banks, Division Archaeologist
Army Corps of Engineers
1114 Commerce Street
Dallas, Texas 75242
(214) 767-4520

Carole Crumley
Professor of Anthropology
301 Alumni Hall 004A
U. of North Carolina at Chapel Hill
Chapel Hill, NC 27514
(919) 962-5527 (Office)
(919) 929-4863 (Home)

William Fitzhugh
Department of Anthropology
National Museum of Natural History
Smithsonian Institution
Washington, DC 20560

George C. Frison
Dept. of Anthropology
University of Wyoming
Laramie, WY 82070
(307) 766-5136

Daniel Gross
Anthropology Program
National Science Foundation
Washington, DC 20550
(202) 357-7804

Cynthia Irwin-Williams
Director of Social Science Center
Desert Research Institute
University of Nevada
P. O. Box 60220
Reno, Nevada 89506
(702) 673-7302

Glyn Isaac
Dept. of Anthropology
Harvard University
Cambridge, MA 02138

Thomas W. Jacobsen, Director
Program in Classical Archaeology
Indiana University
Bloomington, IN 47405
(812) 335-1421

Richard S. MacNeish
Dept. of Archaeology
Boston University
232 Bay State Road
Boston, MA 02215
(617) 353-3415
(617) 470-0840

Charles R. McGimsey, III
Arkansas Archeological Survey
P. O. Box 1249
Fayetteville, AR 72702-1249
(501) 575-3556

James Muhly
Department of Oriental Studies
Williams Hall
University of Pennsylvania
Philadelphia, PA 19104
(215) 898-6042

J. Wilson Myers
Department of Humanities
Michigan State University
East Lansing, MI 48823
(517) 355-9669 & 9572

George Rapp, Jr., Dean
College of Letters and Sciences
University of Minnesota at Duluth
Duluth, Minnesota 55812
(218) 726-7201

Bert Salwen
Department of Anthropology
New York University
25 Waverly Place
New York, NY 10003
(212) 598-3257

Joe D. Seger
Cobb Institute of Archaeology
Drawer AR
Mississippi State University
Mississippi State, MS 39762
(601) 325-3826

Eugene Sterud
Research Division
National Endowment for the Humanities
Washington, DC 20506
(202) 786-0207

Patty Jo Watson
Dept. of Anthropology
Washington University
St. Louis, MO 63130
(314) 889-5252

Gordon Willey
Dept. of Anthropology
Harvard University
Cambridge, MA 02138

James Wiseman, Professor
c/o Dumbarton Oaks
1703 32nd Street NW
Washington, DC 20007

John Yellen, Director
Anthropology Program
National Science Foundation
Washington, DC 20550
(202) 357-7804

Appendix B

AGENDA
Conference on Remote Sensing in Archaeology

Wednesday, February 29, 1984

8:00 PM	Reception, Ramada Inn, Slidell, LA	

Thursday, March 1, 1984

9:00 AM	Welcome (Gainesville Room)	D. W. Mooneyhan, Director Earth Resources Laboratory James Wiseman, Chairman CCONAS Committee on Remote Sensing
9:30	Tutorial	Gene Zetka
10:30	Sensors	Gerry Meeks
11:15	Tour (Building 1210)	
12:00-1:00	Lunch	
1:00-5:00	Demonstrations:	

Archeology	Tom Sever
Soils	Ken Langran
Geology	Doug Rickman
Mines	Dale Quattrochi
Mount St. Helens	Gene Zetka
Olympic	Bill Cibula
Geobotany	Bill Cibula
Corridor Analysis	David Brannon

Friday, March 2, 1984

9:00 AM (Gainesville Room) Discussions chaired by Professor Wiseman

The day will be devoted to discussions of the implications for archaeology of the new technology, and of what steps should be taken to insure the efficient application of remote sensing to the most appropriate, significant problems. Participants will be invited to engage in open discussion of any relevant topic, but also will be asked to address at least the following specific concerns.

1. What areas of archaeological research offer the greatest potential for increased, significant knowledge and/or improved methodology through the application of remote sensing?

2. Which archaeological problems should be the first focus of projects involving remote sensing by NASA?

3. What are the best criteria for determining the answers to No. 2?

4. What other problems might NASA and the discipline of archaeology jointly address in the future that would most benefit the further development of remote sensing and archaeological methodology?

5. What guidelines should be established for the activities of the CCONAS Committee on Remote Sensing? How may it best serve as liaison between NASA and the discipline?

6. What is the future role of the conference participants as an advisory council? How may its views best be disseminated?

GLOSSARY OF TERMS[1]

Absorptance: A measure of the ability of a surface to absorb incident energy, often at specific wavelengths. (A)

Absorption: The process by which radiant energy is absorbed and converted into other forms of energy. (A)

Absorption band: A range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by a substance. (A)

Absorption spectrum: The array of absorption lines and absorption bands that results from the passage of radiant energy from a continuous source through a selectively absorbing medium cooler than the source. (A)

Absorptivity: The capacity of a material to absorb incident radiant energy. A special case of absorptance, it is a fundamental property of material that has a specular (optically smooth) surface and is sufficiently thick to be opaque. It may be further qualified as spectral absorptivity. The suffix (-ity) implies a property intrinsic with a given material, a limiting value. (A)

Accuracy: The success in estimating the true value. The closeness of an estimate of a characteristic to the true value of the characteristic of the population. (D)

Active system: A remote sensing system that transmits its own electromagnetic emanations at an object(s) and then records the energy reflected or refracted back to the sensor. (A)

Active microwave: Ordinarily referred to as a radar. (A)

Additive color process: A method for creating essentially all colors through the addition of light of the three additive color primaries (blue, green, and red) in various proportions through the use of three separate projectors. In this type of process, each primary filter absorbs the other two primary colors and transmits only about one-third of the luminous energy of the source. It also precludes the possibility of mixing colors with a single light source because the addition of a second primary color results in total absorption of the light transmitted by the first color. (A)

Aerial photograph, vertical: An aerial photograph made with the optical axis of the camera approximately perpendicular to the Earth's surface and with the film as nearly horizontal as is practicable. (A)

Aerial reconnaissance: The securing of information by aerial photography or by visual observation from the air. (A)

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[1] Sources:

(A) Reeves (ed.) *Manual of Remote Sensing.*
(B) Swain and Davis, *Remote Sensing: The Quantitative Approach*
(C) Sabins, *Remote Sensing: Principles and Interpretation.*
(D) *Glossary of Statistical, Remote Sensing, and Image Processing Terms*, Esl, Ind. (unpublished).

Albedo: (1) The ratio of the amount of EMR reflected by a body to the amount incident upon it, often expressed as a percentage, e.g., the albedo of the Earth is 34 percent. (2) The reflectivity of a body as compared to that of a perfectly diffusing surface at the same distance from the Sun, and normal to the incident radiation. (A)

Algorithm: (1) A fixed step-by-step procedure to accomplish a given result; usually a simplified procedure for solving a complex problem; also a full statement of a finite number of steps. (2) A computer-oriented procedure for resolving a problem. (D)

Alphanumeric: A character set composed of letters, integers, punctuation marks, and special symbols. Usually the number of characters in a set varies between forty-eight and sixty-four. (D)

Analog: A form of data display in which values are shown in graphic form, such as curves. Also a form of computing in which values are represented by directly measurable quantities, such as voltages or resistances. Analog computing methods contrast with digital methods in which values are treated numerically. (A)

Ancillary data: In remote sensing, secondary data pertaining to the area or classes of interest, such as topographical, demographic, or climatological data. Ancillary data may be digitized and used in the analysis process in conjunction with the primary remote sensing data. (B)

Angle of depression: In SLAR usage, the angle between the horizontal plane passing through the antenna and the line connecting the antenna and the target. (C)

Angle of incidence: (1) The angle between the direction of incoming EMR and the normal to the intercepting surface; (2) In SLAR systems this is the angle between the vertical and a line connecting antenna and target. (C)

Angle of reflection: The angle that EMR reflected from a surface makes with the perpendicular (normal) to the surface. (A)

Angle of view: The angle subtended by lines that pass through the center of the lens to diametrically opposite corners of the plate or film used. (A)

Angstrom (Å): Unit of measurement, 10^{-10} m. (A)

Anomaly: An area on an image that differs from the surrounding normal area. For example, a concentration of vegetation within a desert scene constitutes an anomaly. (C)

Atmospheric windows: Those wavelength ranges in which radiation can pass through the atmosphere with relatively little attenuation; in the optical portion of the spectrum, approximately 0.3-2.5, 3.0-4.0, 4.2-5.0, and 7.0-15.0 μm. (B)

Attenuation: In physics, any process in which the flux density (or power, amplitude, intensity, illuminance) of a "parallel beam" of energy decreases with increasing distance from the energy source. (A)

Attitude: The angular orientation of a remote sensing system with respect to a geographical reference system. (C)

Azimuth: The geographical orientation of a line given as an angle measured clockwise from north. (C)

Background: Any effect in a sensor or other apparatus or system, above which the phenomenon of interest must manifest itself before it can be observed. (See background noise.) (A)

Background luminance: In visual-range theory, the luminance (brightness) of the background against which a target is viewed. (A)

Background noise: (1) In recording and reproducing, the total system noise independent of whether or not a signal is present. The signal is not to be included as part of the noise. (2) In receivers, the noise in the absence of signal modulation on the carrier. Ambient noise detected, measured, or recorded with the signal becomes part of the background noise. Included in this definition is the interference resulting from primary power supplies, which separately is commonly described as hum. (A)

Backscatter: The scattering of radiant energy into the hemisphere of space bounded by a plane normal to the direction of the incident radiation and lying on the same side as the incident ray; the opposite of forward scatter. Also called backscattering. (A)

Band: (1) A selection of wavelengths. (2) Frequency band. (3) Absorption band. (4) A group of tracks on a magnetic drum. (5) A range of radar frequencies, such as X-band, Q-band, etc. (A)

Band-pass filter: A wave filter that has a single transmission band extending from a lower cutoff frequency greater than zero to a finite upper cutoff frequency. (A)

Bandwidth: (1) In an antenna, the range of frequencies within which its performance, with respect to some characteristic, conforms to a specified standard. (2) In a wave, the least frequency interval outside which the power spectrum of a time-varying quantity is everywhere less than some specified fraction of its value at a reference frequency. (3) The number of cycles per second between the limits of a frequency band. (A)

Base-height ratio: Air base (ground distance between centers of successive overlapping photos) divided by aircraft height. This ratio determines vertical exaggeration on stereo models. (C)

Batch processing: A method whereby items are coded and collected into groups and then processed sequentially. (D)

Beam: A focused pulse of energy. (C)

Blackbody, black body (symbol bb used as subscript): An ideal emitter which radiates energy at the maximum possible rate per unit area at each wavelength for any given temperature. A blackbody also absorbs all the radiant energy incident upon it. No actual substance behaves as a true blackbody, although platinum black and other soots rather closely approximate this ideal. In accordance with Kirchhoff's law, a blackbody not only absorbs all wavelengths, but also emits at all wavelengths and does so with maximum possible intensity for any given temperature. (A)

Blackbody radiation: The electromagnetic radiation emitted by an ideal blackbody; it is the theoretical maximum amount of radiant energy of all wavelengths that can be emitted by a body at a given temperature. The spectral distribution of blackbody radiation is described by Planck's law and related radiation laws. (A)

Brightness: (1) The attribute of visual perception in accordance with which an area appears to emit more or less light. (2) Luminance. (3) The luminous flux emitted or reflected per unit projected area per unit solid angle. The unit of brightness, the lambert, is defined as brightness of a surface which emits or reflects one/π lumen per square centimeter per steradian. (A)

Brightness temperature: (1) The temperature of a blackbody radiating the same amount of energy per unit area at the wavelengths under consideration as the observed body. Also called effective temperature. (2) The apparent temperature of a nonblackbody determined by measurement with an optical pyrometer or radiometer. (A)

Calibration: The act or process of comparing certain specific measurements in an instrument with a standard. (A)

Camera, multiband: A camera that exposes different areas of one film, or more than one film, through one lens and a beam splitter, or two or more lenses equipped with different filters, to provide two or more photographs in different spectral bands. (A)

Category: Each unit is assumed to be of one and only one given type. The set of types is called the set of "classes" or "categories," each type being a particular category. The categories are chosen specifically by the investigator as being the ones of interest to him. (D)

Cathode ray tube (CRT): A vacuum tube capable of producing a black-and-white or color image by beaming electrons onto a sensitized screen. As a component of a data-processing system, the CRT can be used to provide rapid, pictorial access to numerical data. (B)

Cell: An area on the ground from which EMR is emitted or reflected. (A)

Change-detection images: Images prepared by digitally comparing two original images acquired at different times. The gray tones of each pixel on a change-detection image portray the amount of difference between the original images. (C)

Chopper: A device, usually one that rotates, used to interrupt a continuous wave signal in a transmitter, receiver, or sensor. (A)

Class: A surface characteristic type that is of interest to the investigator, such as forest by type and condition, or water by sediment load. (D)

Classification: The process of assigning individual pixels of a multispectral image to categories, generally on the basis of spectral reflectance characteristics. (C)

Clustering: The analysis of a set of measurement vectors to detect their inherent tendency to form clusters in multidimensional measurement space. (B)

Color: That property of an object which is dependent on the wavelength of the light it reflects or, in the case of a luminescent body, the wavelength of light that it emits. If, in either case, this light is of a single wavelength, the color seen is a pure spectral color; but if light of two or more wavelengths is emitted, the color will be mixed. White light is a balanced mixture of all the visible spectral colors. (A)

Color balance: The proper intensities of colors in a color print, positive transparency, or negative, that give a correct reproduction of the gray scale (as faithful as can be achieved by photographic representation of the true colors of a scene.) (A)

Color composite (multiband photography): A color picture produced by assigning a color to a particular spectral band. In Landsat, blue is ordinarily assigned to MSS band 4 (0.5-0.6 μm), green to band 5 (0.6-0.7 μm), and red to band 7 (0.8-1.1 μm), to form a picture closely approximating a color-infrared photograph. (A)

Color infrared film: Photographic film sensitive to energy in the visible and near-infrared wavelengths, generally from 0.4-0.9 μm; usually used with a minus-blue (yellow) filter, which results in an effective film sensitivity of 0.5-0.9 μm. Color infrared film is especially useful for detecting changes in the condition of the vegetative canopy which are often manifested in the near-infrared region of the spectrum. Note that color infrared film is not sensitive in the thermal infrared region and therefore cannot be used as a heat-sensitive detector. (B)

Color temperature: An estimate of the temperature of an incandescent body, determined by observing the wavelength at which it is emitting with peak intensity (its color), determined by applying the Wien law. (A)

Computer-compatible tapes: Tapes containing digital Landsat data. These tapes are standard 19-cm (7½-in) wide magnetic tapes in 9-track or 7-track format. Four tapes are required for the four-band multispectral digital data corresponding to one Landsat scene. (D)

Continuous spectrum: (1) A spectrum in which wavelengths, wavenumbers, and frequencies are represented by the continuum of real numbers or a portion thereof, rather than by a discrete sequence of numbers. See absorption spectrum. (2) For EMR, a spectrum that exhibits no detailed structure and represents a gradual variation of intensity with wavelength from one end to the other, as the spectrum from an incandescent solid. (A)

Contrast stretching: Improving the contrast of images by digital processing. The original range of digital values is expanded to utilize the full contrast range of the recording film or display device. (C)

Coordinates, geographical: A system of spherical coordinates for describing the positions of points on the Earth. The declinations and polar bearings in this system are the latitudes and longitudes, respectively. (A)

Covariance: The measure of how two variables change in relation to each other (covariability). If larger values of Y tend to be associated with larger values of X, the covariance will be positive. If larger values of Y are associated with smaller values of X, the covariance will be negative. When there is no particular association between X and Y, the covariance value will approach zero. (D)

Cultural features: All map detail representing man-made elements of the landscape. (D)

Cursor: Aiming device, such as a lens with cross-hairs, on a digitizer or an interactive computer display. (D)

Data acquisition system: The collection of devices and media that measures physical variables and records them prior to input to the data processing system. (B)

Data bank: A well-defined collection of data, usually of the same general type, which can be accessed by a computer. (B)

Data dimensionality: The number of variables (e.g., channels) present in the data set. The term "intrinsic dimensionality" refers to the smallest number of variables that could be used to represent the data set accurately. (B)

Data processing: Application of procedures–mechanical electrical, computation, or other–whereby data are changed from one form into another. (A)

Data reduction: Transformation of observed values into useful, ordered, or simplified information. (A)

Decision rule (or classification rule): The criterion used to establish discriminant functions for classification (e.g., nearest-neighbor rule, minimum-distance-to-means rule, maximum-likelihood rule). (B)

Density (symbol, D): A measure of the degree of blackening of an exposed film, plate, or paper after development, or of the direct image (in the case of a printout material). It is defined strictly as the logarithm of the optical opacity, where the opacity is the ratio of the incident to the transmitted (or reflected) light or transmissivity, T, as $D = \log(1/T)$. (A)

Density slicing: The process of converting the continuous gray tone of an image into a series of density intervals, or slices, each corresponding to a specific digital range. (C)

Detection: A unit is said to be "detected" if the decision rule is able to assign it as belonging only to some given subset of categories from the set of all categories. Detection of a unit does not imply that the decision rule is able to identify the unit as specifically belonging to one particular category. (D)

Detector (radiation): A device providing an electrical output that is a useful measure of incident radiation. It is broadly divisible into two groups: thermal (sensitive to temperature changes), and photodetectors (sensitive to changes in photon flux incident on the detector), or it may also include antennas and film. Typical thermal detectors are thermocouples, thermopiles, and thermistors; the latter is termed a bolometer. (A)

Dielectric constant: Electrical property of matter that influences radar returns; also referred to as complex dielectric constant. (C)

Diffraction: The propagation of EMR around the edges of opaque objects into the shadow region. A point of light seen or projected through a circular aperture will always be imaged as a bright center surrounded by light rings of gradually diminishing intensity in the shadow region. Such a pattern is called a diffraction disk, Airy disk, or centric. (A)

Diffuse reflection: The type of reflection obtained from a relatively rough (in terms of the wavelength of the EMR) surface, in which the reflected rays are scattered in all directions. (A)

Diffuse reflector: Any surface that reflects incident rays in many directions, either because of irregularities in the surface or because the material is optically inhomogeneous, as a paint; the opposite of a specular reflector. Ordinary writing papers are good examples of diffuse reflectors, whereas mirrors or highly polished plates are examples of specular reflectors in the visible portion of the EM spectrum. Almost all terrestrial surfaces (except calm water) act as diffuse reflectors of incident solar radiation. The smoothness or roughness of a surface depends on the wavelength of the incident EMR. (A)

Diffuse sky radiation: Solar radiation reaching the Earth's surface after having been scattered from the direct solar beam by molecules or suspensoids in the atmosphere. Also called skylight, diffuse skylight, sky radiation. (A)

Digitization: The process of converting an image recorded originally on photographic material into numerical format. (C)

Discriminant function: One of a set of mathematical functions which in remote sensing are commonly derived from training samples and a decision rule, and are used to divide the measurement space into decision regions. (B)

Display: An output device that produces a visible representation of a data set for quick visual access; usually the primary hardware component is a cathode ray tube. (B)

Distribution function: The relative frequency with which different values of a variable occur. (D)

DN: Digital number. The value of reflectance recorded for each pixel on Landsat CCT's. (C)

Edge: The boundary of an object in a photograph or image, usually characterized by a rather drastic change in the gray shade value from the immediate interior of the boundary to the immediate exterior of the boundary. (D)

Edge enhancement: The use of analytical techniques to emphasize transition in imagery. (A)

Electromagnetic radiation (EMR): Energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields. The term radiation, alone, is commonly used for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy. (A)

Electromagnetic spectrum: The ordered array of known electromagnetic radiations extending from the shortest cosmic rays, through gamma rays, X-rays, ultraviolet radiation, visible radiation, infrared radiation, and including microwave and all other wavelengths of radio energy. (A)

Element: The smallest definable object of interest in the survey. It is a single item in a collection, population, or sample. (D)

Emission: With respect to EMR, the process by which a body emits EMR usually as a consequence of its temperature only. (A)

Emissivity: The ratio of the radiation given off by a surface to the radiation given off by a blackbody at the same temperature; a blackbody has an emissivity of 1, other objects between 0 and 1. (B)

Emittance: The obsolete term for the radiant flux per unit area emitted by a body, or exitance. (A)

Environment: An external condition, or the sum of such conditions, in which a piece of equipment or a system operates, as in temperature environment, vibration environment, or space environment. The environments are usually specified by a range of values, and may be either natural or artificial. (A)

Ephemeral data: Data that: (1) help to characterize the conditions under which the remote sensing data were collected: (2) may be used to calibrate the sensor data prior to analysis; (3) include such information as the positioning and spectral stability of sensors, Sun angle, platform attitude, etc. (B)

Equivalent blackbody temperature: The temperature measured radiometrically corresponding to that which a blackbody would have. Most natural objects including soil, plant leaves, and water have emissivities greater than 0.9 but less than 1.0. (A)

Exitance (symbol, M): The radiant flux per unit area emitted by a body or surface. (A)

False color: The use of one color to represent another; for example, the use of red emulsion to represent infrared light in color infrared film. (A)

Far range: Refers to the portion of an SLAR image farthest from the aircraft flight path. (C)

Feature: An n-tuple or vector with components which are functions of the initial measurement pattern variables or some subsequence of the measurement n-tuples. Feature n-tuples or vectors frequently have fewer components than the initial measurement vectors and are designed to contain a high amount of information about the discrimination between units of the types of categories in the given category set. Features often contain information about gray shade, texture, shape or context. Also, a cartographic type in digital form appearing as part of the descriptor in coded form (Feature Code). (D)

Feature extraction: The process in which an initial measurement pattern or some subsequence of measurement patterns is transformed to a new pattern feature. (D)

Field of view: The solid angle through which an instrument is sensitive to radiation. Owing to various effects, diffractions, etc., the edges are not sharp. In practice they are defined as the "half-power" points, i.e., the angle outwards from the optical axis, at which the energy sensed by the radiometer drops to half its on-axis value. (A)

Filter: (1, noun) Any material which, by absorption or reflection, selectively modifies the radiation transmitted through an optical system. (2, verb) To remove a certain component or components of EMR, usually by means of a filter, although other devices may be used. (A)

Filtering: In analysis, the removal of certain spectral or spatial frequencies to highlight features in the remaining image. (A)

Focus: The point at which the rays from a point source of light reunite and cross after passing through a camera lens. In practice, the plane in which a sharp image of any scene is formed. (A)

Format: The arrangement of descriptive data in descriptors, identifiers, or labels. The arrangement of data in bit, byte, and word form in the CPU. (D)

Frame: Complete tape of a single or multidate Landsat frame covering roughly an area about 100 nautical miles square. (D)

Frequency: Number of oscillations per unit time or number of wavelengths that pass a point per unit time. (D)

Frequency response: (1) Response of a system as a function of the frequency of excitations. (2) The portion of the frequency spectrum that can be sensed by a device within specified limits of amplitude error. (A)

Gain: (1) A general term used to denote an increase in signal power in transmission from one point to another. Gain is usually expressed in decibels. (2) An increase or amplification. (A)

Gamma: A numerical measure of the extent to which a negative has been developed, indicating the proportion borne by the contrast of the negative to that of the subject on which it was exposed. The numerical figure for gamma is the tangent of the straight-line (correct exposure portion of the curve resulting from plotting exposure against density. (A)

GCP: Ground control point. A geographical feature of known location that is recognizable on images and can be used to determine geometrical corrections. (C)

Geocoding: Geographical referencing or coding of location of data items. (D)

Geometrical transformations: Adjustments made in the image data to change its geometrical character, usually to improve its geometrical consistency or cartographic utility. (B)

Gray body: A radiating surface whose radiation has essentially the same spectral energy distribution as that of a blackbody at the same temperature, but whose emissive power is less. Its absorptivity is nonselective. Also spelled *grey* body. (A)

Gray scale: A monochrome strip of shades ranging from white to black with intermediate shades of gray. The scale is placed in a setup for color photograph and serves as a means of balancing the separation negatives and positive dye images. (A)

Grid line: One of the lines in a grid system; a line used to divide a map into squares. East-west lines in a grid sytem are x-lines, and north-south lines are y-lines. (A)

Ground data: Supporting data collected on the ground, and information derived therefrom, as an aid to the interpretation of remotely recorded surveys, such as airborne imagery, etc. Generally, this should be performed concurrently with the airborne surveys. Data as to weather, soils and vegetation types and conditions are typical. (A)

Ground range: The distance from the ground track (nadir) to a given object. (A)

Ground resolution cell: The area on the terrain that is covered by the instantaneous field of view of a detector. The size of the ground resolution cell is determined by the altitude of the remote-sensing system and the instantaneous field of view of the detector. (C)

Ground track: The vertical projection of the actual flight path of an aerial or space vehicle onto the surface of the Earth or other body. (A)

Ground truth (jargon): Term coined for data and information obtained on surface or subsurface features to aid in interpretation of remotely sensed data. Ground data and ground information are preferred terms. (A)

H-D (Hurter-Driffield) Curve: A graph showing the relationship of exposure to (photo) density, where the density is plotted against the logarithm of the exposure (also known as characteristic curve). (A)

Hardware: The physical components of a computer and its peripheral equipment. Contrasted with software. (D)

Histogram: The graphical display of a set of data which shows the frequency of occurrence (along the vertical axis) of individual measurements or values (along the horizontal axis); a frequency distribution. (B)

Hue: That attribute of a color by virtue of which it differs from gray of the same brilliance, and which allows it to be classed as red, yellow, green, blue, or intermediate shades of these colors. (A)

Illumination: The intensity of light striking a unit surface is known as the specific illumination or luminous flux. It varies directly with the intensity of the light source and inversely as the square of the distance between the illuminated surface and the source. It is measured in a unit called the lux. The total illumination is obtained by multiplying the specific illumination by the area of the surface covered by the light. The unit of total illumination is the lumen. (A)

Image: (1) The counterpart of an object produced by the reflection or refraction of light when focused by a lens or mirror. (2) The recorded representation (commonly as a photo-image) of an object produced by optical, electro-optical, optical mechanical, or electronic means. It is generally used when the EMR emitted or reflected from a scene is not directly recorded on film. (A)

Image Enhancement: Any one of a group of operations that improve the detectability of the targets or categories. These operations include, but are not limited to, contrast improvement, edge enhancement, spatial filtering, noise supression, image smoothing, and image sharpening. (D)

Image Processing: Encompasses all the various operations that can be applied to photographic or image data. These include, but are not limited to, image compression, image restoration, image enhancement, preprocessing, quantization, spatial filtering and other image pattern recognition techniques. (D)

Image Restoration: A process by which a degraded image is restored to its original condition. Image restoration is possible only to the extent that the degradation transform is mathematically invertible. (D)

Incident ray: A ray impinging on a surface. (A)

Infrared: Pertaining to energy in the 0.7-100 μm wavelength region of the electromagnetic spectrum. For remote sensing, the infrared wavelengths are often subdivided into near infrared (0.7-1.3 μm), middle infrared (1.3-3.0 μm), and far infrared (7.0-15.0 μm). Far infrared is sometimes referred to as thermal or emissive infrared. (B)

Infrared, photographic: Pertaining to or designating the portion of the EM spectrum with wavelengths just beyond the red end of the visible spectrum; generally defined as from 0.7 to about 0.1 μm, or the useful limits of film sensitivities. (A)

Insolation: Incident solar energy. (C)

Instantaneous field of view: (IFOV) A term specifically denoting the narrow field of view designed into detectors, particularly scanning radiometer systems, so that, while as much as 120° may be under scan, only EMR from a small area is being recorded at any one instant. (A)

Interactive image processing: The use of an operator or analyst at a console that provides the means of assessing, preprocessing, feature extracting, classifying, identifying, and displaying the original imagery or the processed imagery for his subjective evaluations and further interactions. (D)

Irradiance: The measure, in power units, of radiant flux incident upon a surface. It has the dimensions of energy per unit time (e.g., watts). (A)

Irradiation: The impinging of EMR on an object or surface. (A)

Kelvin: A thermometer scale starting at absolute zero (-273°C approximately) and having degrees of the same magnitude as those of the Celsius thermometer. Thus, 0°C = 273°K; 100°C = 373 °K; etc.; also called the absolute scale, thermodynamic temperature scale. (A)

Kinetic temperature: The internal temperature of an object, which is determined by the molecular motion. Kinetic temperature is measured with a contact thermometer, and differs from radiant temperature, which is a function of emissivity and internal temperature. (C)

Kirchhoff's Law: The radiation law which states that at a given temperature the ratio of the emissivity to the absorptivity for a given wavelength is the same for all bodies and is equal to the emissivity of an ideal blackbody at that temperature and wavelength. This important law asserts that good absorbers of a given wavelength are also good emitters of the wavelength. (A)

Lambertian surface: An ideal, perfectly diffusing surface, which reflects energy equally in all directions. (B)

Large scale: (1) Aerial photography with a representative fraction of 1:500 to 1:10,000. (2) Maps with a representative fraction (scale) greater than 1:100,000. (A)

Layover: Displacement of the top of an elevated feature with respect to its base on the radar image. The peaks look like dip-slopes. (A)

Light: Visible radiation (about 0.4-0.7 μm in wavelength) considered in terms of its luminous efficiency; i.e., evaluated in proportion to its ability to stimulate the sense of sight. (A)

Line, flight: A line drawn on a map or chart to represent the track over which an aircraft has been flown or is to fly. The line connecting the principal points of vertical aerial photographs. (A)

Lineament: A linear topographical or tonal feature on the terrain and on images and maps, which may represent a zone of structural weakness. (C)

Linear feature: A two-dimensional, straight to somewhat curved (usually) line, linear pattern, or alignment of discontinuous patterns evident in an image, photo, a map, which represents the expression of some degree of linearity of a single or diverse grouping of natural or cultural ground features. (Definition by N.M. Short.)

Look direction: Direction in which pulses of microwave energy are transmitted by an SLAR system. Look direction is normal to the azimuth direction. Also called range direction. (C)

Luminance: In photometry, a measure of the intrinsic luminous intensity emitted by a source in a given direction; the illuminance produced by light from the source upon a unit surface area oriented normal to the line of sight at any distance from the source, divided by the solid angle subtended by the source at the receiving surface. Also called brightness (luminance is preferred). (A)

Map: A representation in a plane surface, at an established scale, of the physical features (natural, artificial, or both) of a part of the Earth's surface, with the means of orientation indicated. (A)

Map, large-scale: A map having a scale of 1:100,000 or larger. (A)

Map, medium-scale: A map having a scale from 1:100,000, exclusive, to 1:1,000,000, inclusive. (A)

Map, small-scale: A map having a scale smaller than 1:1,000,000. (A)

Map, thematic: A map designed to demonstrate particular features or concepts. In conventional use this term excludes topographical maps. (D)

Maximum likelihood rule: A statistical decision criterion to assist in the classification of overlapping signatures; pixels are assigned to the class of highest probability.

Mie scattering: Multiple reflection of light waves by atmospheric particles that have the approximate dimensions of the wavelength of light. (C)

Micrometer (abbr. μm): A unit of length equal to one-millionth (10^{-6}) of a meter or one-thousandth (10^{-3}) of a millimeter. (A)

Micron (abbr. μ): Equivalent to and replaced by micrometer; 10^{-6} m. (A)

Microwave: Electromagnetic radiation having wavelengths between 1 m and 1 mm or 300-0.3 GHz in frequency, bounded on the short wavelength side by the far infrared (at 1 mm) and on the long wavelength side by very high-frequency radio waves. Passive systems operating at these wavelengths are sometimes called microwave systems. Active systems are called radar, although the literal definition of radar requires a distance-measuring capability not always included in active systems. The exact limits of the microwave region are not defined. (A)

Minimum distance classifier: A classification technique that assigns raw data to the class whose mean falls the shortest Euclidean distance from it.

Mosaic: An assemblage of overlapping aerial or space photographs or images whose edges have been matched to form a continuous pictorial representation of a portion of the Earth's surface. (A)

Mosaic, controlled: A mosaic that is laid to ground control and uses prints that have been rectified as shown to be necessary by the control. (A)

Mosaicking: The assembling of photographs or other images whose edges are cut and matched to form a continuous photographic representation of a portion of the Earth's surface. (A)

Multiband system: A system for simultaneously observing the same (small) target with several filtered bands, through which data can be recorded. Usually applied to cameras; may be used for scanning radiometers that use dispersant optics to split wavelength bands apart for viewing by several filtered detectors. (A)

Multichannel system: Usually used for scanning systems capable of observing and recording several channels of data simultaneously, preferably through the same aperture. (A)

Multispectral: Generally used for remote sensing in two or more spectral bands, such as visible and IR. (A)

Multispectral (line) scanner: A remote sensing device that operates on the same principle as the infrared scanner, except that it is capable of recording data in the ultraviolet and visible portions of the spectrum as well as the infrared. (A)

Multivariate analysis: A data-analysis approach that makes use of multidimensional interrelations and correlations within the data for effective discrimination. (B)

Nadir: (1) That point on the celestial sphere vertically below the observer, or 180° from the zenith. (2) That point on the ground vertically beneath the perspective center of the camera lens. (A)

Nautical mile (abbr. knot): A unit of distance used principally in navigation. For practical navigation it is usually considered the length of one minute of any great circle of the Earth, the meridian being the great circle most commonly used. Also called sea mile. (A)

Near range: Refers to the portion of an SLAR image closest to the aircraft flight path. (C)

Noise: Random or regular interfering effects in the data which degrade its information-bearing quality. (B)

Orbit: The path of a satellite around a body under the influence of gravity. (C)

Overlap: The area common to two successive photos along the same flight strip; the amount of overlap is expressed as a percentage of photo area. Also called endlap. (A)

Overlay: (1) A transparent sheet giving information to supplement that shown on maps. When the overlay is laid over the map on which it is based, its details will supplement the map. (2) A tracing of selected details on a photograph, mosaic, or map to present the interpreted features and the pertinent detail. (A)

Panchromatic: Used for films that are sensitive to broadband (e.g., entire visible part of spectrum) EMR, and for broadband photographs. (A)

Passive system: A sensing system that detects or measures radiation emitted by the target. Compare active system. (A)

Pattern: (1) In a photo image, the regularity and characteristic placement of tones or textures. Some descriptive adjectives for patterns are regular, irregular, random, concentric, radial, and rectangular. (2) The relations between any more-or-less independent parameters of a response, e.g., the pattern in the frequency domain of the response from an object. (A)

Pattern recognition: Concerned with, but not limited to, problems of:

1. pattern discrimination,
2. pattern classification,
3. feature selection,
4. pattern identification,
5. cluster identification,
6. feature extraction,
7. preprocessing,
8. filtering,
9. enhancement,
10. pattern segmentation,
11. screening. (D)

Perspective: Representation, on a plane or curved surface, of natural objects as they appear to the eye. (A)

Photogrammetry: The art or science of obtaining reliable measurements by means of photography. (A)

Photograph: A picture formed by the action of light on a base material coated with a sensitized solution that is chemically treated to fix the image points at the desired density. Usually now taken to mean the direct action of EMR on the sensitized material. Compare image. (A)

Photographic interpretation: The act of examining photographic images for the purpose of identifying objects and judging their significance. Photo interpretation, photointerpretation, and image interpretation are other widely used terms. (A)

Pitch: Rotation of an aircraft about the horizontal axis normal to its longitudinal axis, which causes a nose-up nose-down attitude. (C)

Picture: Representation of a scene by a photographic positive print or transparency, made from a negative, produced by the direct action of actinic (visible) light or EMR outside the visible part of the spectrum and converted into visible EMR by an optical-mechanical or wholly electronic scanner. (A)

Pixel: (Derived from "picture element.") A data element having both spatial and spectral aspects. The spatial variable defines the apparent size of the resolution cell (i.e., the area on the ground represented by the data values), and the spectral variable defines the intensity of the spectral response for that cell in a particular channel. (B)

Planck's Law: An expression for the variation of monochromatic emittance (emissive power) as a function of wavelength of blackbody radiation at a given temperature; it is the most fundamental of the radiation laws. (A)

Polarization: The direction of vibration of the electrical field vector of electromagnetic radiation. In SLAR systems polarization is either horizontal or vertical. (C)

Precision: A measure of the dispersion of the values observed when measuring a characteristic of elements of a population. The clustering of sample values about their own average. (D)

Pulse: (1) A variation of a quantity whose value is normally constant; this variation is characterized by a rise and a decay, and has a finite duration. (2) A short burst of EMR transmitted by the radar. (A)

Radar: Acronym for radio detection and ranging. A method, system or technique, including equipment components, for using beamed, reflected, and timed EMR to detect, locate, and (or) track objects, to measure altitude and to acquire a terrain image. In remote sensing of the Earth's or a planetary surface, it is used for measuring and, often, mapping the scattering properties of the surface. (A)

Radar beam: The vertical fan-shaped beam of EM energy produced by the radar transmitter. (A)

Radar shadow: A dark area of no return on a radar image that extends in the far-range direction from an object on the terrain that intercepts the radar beam. (C)

Radiance: The accepted term for radiant flux in power units (e.g., W) and not for flux density per solid angle (e.g., W cm^{-2} sr^{-1}) as often found in recent publications. (A)

Radiant flux: The time rate of the flow of radiant energy; radiant power. (B)

Radiant power: Rate of change of radiant energy with time. May be further qualified as spectral radiant power, at a given wavelength. (A)

Radiant temperature: Concentration of the radiant flux from a material. Radiant temperature is the product of the kinetic temperature multiplied by the emissivity to the one-fourth power. (C)

Radiation: The emission and propagation of energy through space or through a material medium in the form of waves; for example, the emission and propagation of EM waves, or of sound and elastic waves. The process of emitting radiant energy. (A)

Radiometer: An instrument for quantitively measuring the intensity of EMR in some band of wavelengths in any part of the EM spectrum. Usually used with a modifier, such as an IR radiometer or a microwave radiometer. (A)

Radiometric correction: Correcting gain and offset variations in MSS data. Procedure calibrates and corrects the radiation data provided by the Landsat sensor detectors.

Range direction: For radar images this is the direction in which energy is transmitted from the antenna and is normal to the azimuth direction. Also called look direction. (C)

Rayleigh-Jeans Law: An approximation to Planck's Law for blackbody radiation valid in the longer (microwave) wavelengths. It is almost always of sufficient accuracy for calculations in the radio and microwave regions of the spectrum. (A)

Rayleigh scattering: The wavelength-dependent scattering of electromagnetic radiation by particles in the atmosphere much smaller than the wavelengths scattered. (B)

Real-aperture radar: SLAR system in which azimuth resolution is determined by the physical length of the antenna and by the wavelength. The radar returns are recorded directly to produce images. Also called brute-force radar. (C)

Real time: Time in which reporting on events or recording of events is simultaneous with the events. For example, the real time of a satellite is the time in which it simultaneously reports its environment as it encounters it; the real time of a computer is the time during which it is accepting data and performing operations on it. (A)

Reflectance: The ratio of the radiant energy reflected by a body to that incident upon it. The suffix (-ance) implies a property of that particular specimen surface. (A)

Reflection (EMR theory): EMR neither absorbed nor transmitted is reflected. Reflection may be diffuse when the incident radiation is scattered upon being reflected from the surface, or specular, when all or most angles of reflection are equal to the angle of incidence. (A)

Reflectivity: A fundamental property of a material that has a reflecting surface and is sufficiently thick to be opaque. One may further qualify it as spectral reflectivity. The suffix (-ity) implies a property intrinsic with a given material, a limiting value. (A)

Refraction: The bending of EMR rays when they pass from one medium into another having a different index of refraction or dielectric coefficient. EMR rays also bend in media that have continuous variations in their indices of refraction or dielectric coefficients. (A)

Registration: The process of geometrically aligning two or more sets of image data such that resolution cells for a single ground area can be digitally or visually superposed. Data being registered may be of the same type, from very different kinds of sensors, or collected at different times. (B)

Remote sensing: In the broadest sense, the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study; e.g., the utilization at a distance (as from an aircraft, spacecraft, or ship) of any device and its attendant display for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, and scintillation counters. (A)

Resolution: The ability of an entire remote sensor system, including lens, antennae, display, exposure, processing, and other factors, to render a sharply defined image. It may be expressed as line pairs per millimeter or meter, or in many other ways. In radar, resolution usually applies to the effective beam-width and range measurement width, often defined as the half-power points. For infrared line scanners the resolution may be expressed as the instantaneous field of view. Resolution may also be expressed in terms of temperature or other physical property being measured. (A)

Resolution cell: The smallest area in a scene considered as a unit of data. For Landsat-1 and -2 the resolution cell approximates a rectangular ground area of 0.44 hectares or 1.1 acres (see pixel, instantaneous field of view). (B)

Reststrahlen (residual) rays: The difference in intensities or radiance at certain frequencies (wavelengths) between the special signatures for the ideal (perfect blackbody) and actual emission curves of a substance.

Return beam vidicon (RBV): A modified vidicon television camera tube, in which the output signal is derived from the depleted electron beam reflected from the tube target. The RBV can be considered as a cross between a vidicon and an orthicon. RBVs provide highest resolution TV imagery, and are used in the ERTS (Landsat) series. (A)

Roll: Rotation of an aircraft about the longitudinal axis to cause a wing-up or wing-down attitude. (C)

Roughness: For radar images this term describes the average vertical relief of small-scale irregularities of the terrain surface. (C)

Sample: A subset of a population selected to obtain information concerning the characteristics of the population. (D)

Sampling rate: The temporal, spatial, or spectral rate at which measurements of physical quantities are taken. Temporally, sampling variables may describe how often data are collected or the rate at which an analog signal is sampled for conversion to digital format; the spatial sampling rate describes the number, ground size, and position of areas where spectral measurements are made; the spectral sampling rate refers to the location and width of the sensor's spectral channels with respect to the electromagnetic spectrum. (B)

Scale: The ratio of a distance on a photograph or map to its corresponding distance on the ground. The scale of a photograph varies from point to point because of displacements caused by tilt and relief, but is usually taken as f/H, where f is the principal distance (focal length) of the camera and H is the height of the camera above mean ground elevation. Scale may be expressed as a ratio 1:24,000; a representative fraction, 1/24,000; or an equivalence, 1 in. = 2,000 ft. (A)

Scan line: The narrow strip on the ground that is swept by the instantaneous field of view of a detector in a scanner system. (C)

Scanner: (1) Any device that scans, and thus produces an image. See scanning radiometer. (2) A radar set incorporating a rotatable antenna, or radiator element, motor drives, mounting, etc. for directing a searching radar beam through space and imparting target information to an indicator. (A)

Scanning radiometer: A radiometer, which by the use of a rotating or oscillating plane mirror, can scan a path normal to the movement of the radiometer. (A)

Scattering: (1) The process by which small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions. (2) The process by which a rough surface reradiates EMR incident upon it. (A)

Scene: In a passive remote sensing system, everything occurring spatially or temporally before the sensor, including the Earth's surface, the energy source, and the atmosphere, that the energy passes through as it travels from its source to the Earth and from the Earth to the sensor. (B)

Sensitivity: The degree to which a detector responds to electromagnetic energy incident upon it. (C)

Sensor: Any device that gathers energy, EMR or other, converts it into a signal and presents it in a form suitable for obtaining information about the environment. (A)

Sidelap: The extent of lateral overlap between images acquired on adjacent flight lines. (C)

Signal: The effect (e.g., pulse of electromagnetic energy) conveyed over a communication path or system. Signals are received by the sensor from the scene and converted to another form for transmission to the processing system. (B)

Signal-to-noise ratio: The ratio of the level of the information-bearing signal power to the level of the noise power. Abbreviated as S/N.

Signature: Any characteristic or series of characteristics by which a material may be recognized in an image, photo, or data set. See also spectral signature. (A)

Signature analysis techniques: Techniques that use the variation in the spectral reflectance or emittance of objects as a method of identifying the objects. (A)

Signature extension: The use of training statistics obtained from one geographical area to classify data from similar areas some distance away; includes consideration of changes in atmosphere, and other geographical and temporal conditions that can cause differences in signal level for single classes of interest (see spectral signature). (B)

Smoothing: The averaging of densities in adjacent areas to produce more gradual transitions. (A)

Slant range: For radar images this term represents the distance measured along a line between the antenna and the target. (C)

Software: The computer programs that drive the hardware components of a data processing system; includes system monitoring programs, programming language processors, data handling utilities, and data analysis programs. (B)

Spatial filter: An image transformation, usually a one-to-one operator used to lessen noise or enhance certain characteristics of the image. For any particular (x, y) coordinate on the transformed image, the spatial filter assigns a gray shade on the basis of the gray shades of a particular spatial pattern near the coordinates (x, y). (D)

Spatial information: Information conveyed by the spatial variations of spectral response (or other physical variables) present in the scene. (B)

Spectral band: An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wavenumbers. (A)

Spectral interval: The width, generally expressed in wavelength or frequency of a particular portion of the electromagnetic spectrum. A given sensor (e.g., radiometer or camera film) is designed to measure or be sensitive to energy received at the satellite from that part of the spectrum. Also termed spectral band. (A)

Spectral reflectance: The reflectance of electromagnetic energy at specified wavelength intervals. (C)

Spectral regions: Conveniently designated ranges of wavelengths subdividing the electromagnetic spectrum; for example, the visible region, X-ray region, infrared region, middle-infrared region. (B)

Spectral response: The response of a material as a function of wavelength to incident electromagnetic energy, particularly in terms of the measurable energy reflected from and emitted by the material. (B)

Spectral signature: Quantitative measurement of the properties of an object at one or several wavelength intervals. (A)

Spectrometer: A device to measure the spectral distribution of EMR. This may be achieved by a dispersive prism, grating, or circular interference filter with a detector placed behind a slit. If one detector is used, the dispersive element is moved so as to sequentially pass all dispersed wavelengths across the slit. In an interferometer-spectrometer, on the other hand, all wavelengths are examined all the time, the scanning effect being achieved by rapidly oscillating two, partly reflective, (usually parallel) plates so that interference fringes are produced. A Fourier transform is required to reconstruct the spectrum. Also called spectroradiometer. (A)

Specular reflection: The reflectance of electromagnetic energy without scattering or diffusion, as from a surface that is smooth in relation to the wavelengths of incident energy. Also called mirror reflection. (B)

Stefan-Boltzmann Law: One of the radiation laws stating that the amount of energy radiated per unit time from a unit surface area of an ideal blackbody is proportional to the fourth power of the absolute temperature of the blackbody. (A)

Steradian: The unit solid angle that cuts unit area from the surface of a sphere of unit radius centered at the vertex of the solid angle. There are 4π steradians in a sphere. (A)

Subtractive color process: A method of creating essentially all colors through the subtraction of light of the three subtractive color primaries (cyan, magenta and yellow) in various proportions through use of a single white light source. (A)

Supervised classification: A computer-implemented process through which each measurement vector is assigned to a class according to a specified decision rule, where the possible classes have been defined on the basis of representative training samples of known identity. (B)

Swath width (total field of view): The overall plane angle or linear ground distance covered by a multispectral scanner in the across-track direction. (B)

Synchronous satellite: An equatorial west-to-east satellite orbiting the Earth at an altitude of 34,900 km, at which altitude it makes one revolution in 24 h synchronous with the Earth's rotation. (A)

Synoptic view: The ability to see or otherwise measure widely dispersed areas at the same time and under the same conditions; e.g., the overall view of a large portion of the Earth's surface which can be obtained from satellite altitudes. (B)

System: Structured organization of people, theory, methods and equipment to carry out an assigned set of tasks. (D)

Target: (1) An object on the terrain of specific interest in a remote sensing investigation. (2) The portion of the Earth's surface that produces by reflection or emission the radiation measured by the remote sensing system. (B,C)

Thermal band: A general term for middle-infrared wavelengths which are transmitted through the atmosphere window at 8-14 μm. Ocasionally also used for the windows around 3-6 μm. (A)

Thermal capacity (symbol, C): The ability of a material to store heat, expressed in cal g^{-1} $°C^{-1}$ (C)

Thermal conductivity (symbol K): The measure of the rate at which heat passes through a material, expressed in cal cm^{-1} s^{-1} $°C^{-1}$. (C)

Thermal crossover: On a plot of radiant temperature versus time, this refers to the point at which the temperature curves for two different materials intersect. (C)

Thermal inertia (symbol, P): A measure of the response of a material to temperature changes, expressed in cal cm^{-2} $°C^{-1}$ $s^{-½}$. (C)

Thermal infrared: The preferred term for the middle wavelength range of the IR region, extending roughly from 3 μm at the end of the near infrared, to about 15 or 20 μm, where the far infrared begins. In practice the limits represent the envelope of energy emitted by the Earth behaving as a gray body with a surface temperature around 290°K (27 °C). (A)

Threshold: The boundary in spectral space beyond which a data point, or pixel, has such a low probability of inclusion in a given class that the pixel is excluded from that class. (D)

Tone: Each distinguishable shade of gray from white to black on an image. (C)

Training: Informing the computer system which sites to analyze for spectral properties or signatures of specific land cover classes; also called signature extraction.

Training samples: The data samples of known identity used to determine decision boundaries in the measurement or feature space prior to classification of the overall set of data vectors from a scene. (B)

Training sites: Recognizable areas on an image with distinct (spectral) properties useful for identifying other similar areas.

Transmissivity: Transmittance for a unit thickness sample. One may further qualify it as spectral transmissivity. The suffix (ity) implies a property intrinsic with a given material. (A)

Transmittance: The ratio of the radiant energy transmitted through a body to that incident upon it. The suffix (-ance) implies a property of that particular specimen. (A)

Ultraviolet radiation: EMR of shorter wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 10 and 4000 Å.

Variance: Variance of a random variable is the expected value of the square of the deviation between that variable and its expected value. It is a measure of the dispersion of the individual unit values about their mean. (D)

Vidicon: (1) A storage-type electronically scanned photoconductive television camera tube, which often has a response to radiations beyond the limits of the visible region. Particularly useful in space applications, as no film is required. (2) An image-plane scanning device. See return beam vidicon. (A)

Vignetting: A gradual reduction in density of parts of a photographic image caused by the stopping of some of the rays entering the lens. (A)

Visible wavelengths: The radiation range in which the human eye is sensitive, approximately 0.4-0.7 μm. (B)

Wavelength (symbol λ): Wavelength = velocity/frequency. In general, the mean distance between maxima (or minima) of a roughly periodic pattern. Specifically, the least distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and IR wavelengths are measured in nanometers (10^{-9} m), micrometers (10^{-6} m) and Angstroms (10^{-10} m). (A)

Wiens Displacement Law: Describes the shift of the radiant power peak to shorter wavelengths with increasing temperature. (C)

Window: A band of the electromagnetic spectrum which offers maximum transmission and minimal attenuation through a particular medium with the use of a specific sensor. (D)

Yaw: Rotation of an aircraft about its vertical axis, causing the longitudinal axis to deviate from the flight line. (C)

Zenith: The point in the celestial sphere that is exactly overhead: opposed to nadir. (A)

ACRONYMS AND ABBREVIATIONS

ADP: Automatic Data Processing
AEM: Applications Explorer Mission
AMS: Army Map Service
ASAP: Advanced Scientific Array Processor
ASCS: Agricultural Stabilization and Conservation Service
ATI: Apparent Thermal Inertia
ATS: Applications Technology Satellite

BPI: Bits per inch

CA: Canonical Analysis
C&D: Chesapeake and Delaware Canal
CCT: Computer Compatible Tape
CRT: Cathode Ray Tube
CZCS: Coastal Zone Color Scanner

DCA: Department of Community Affairs (New Jersey)
DCP: Data Collection Platform
DCS: Data Collection System
DIDS: Domestic Information Display System
DN: Digital Number
DWQ: Division of Water Quality (New Jersey)

EBR: Electron Beam Recorder
ED: Enumeration District
EDC: Eros Data Center (Sioux Falls, S. Dak.)
EDIPS: EDC Digital Image Processing System
EM: Electromagnetic
EMR: Electromagnetic Radiation
EPA: Environmental Protection Agency
ERE: Effective Resolution Element

ACRONYMS (CONT'D.)

ERIS: Earth Resources Inventory System
ERL: Earth Resources Laboratory (Bay St. Louis, Miss.)
EROS: Earth Resources Observing System
ERRSAC: Eastern Regional Remote Sensing Applications Center (Greenbelt, Md.)
ESMR: Electrically Scanned Microwave Radiometer
ESRI: Environmental Systems Research Institute

FOV: Field of View

GCP: Ground Control Point
GE: General Electric (Company)
GES: Geographic Entry System
GIS: Geographic Information System
GOES: Global Operational Environmental Satellite
GPS: Global Positioning System
GSFC: Goddard Space Flight Center

HDT: High Density Tape
Hg-Cd-Te: Mercury-Cadmium-Telluride (Detector)
HOM: Hotine Oblique Mercator
HRIR: High Resolution Infrared Radiometer

IBM: International Business Machines (Inc.)
IDIC: Image Dissector Camera System
IDIMS: Interactive Digital Image Manipulation System
IFOV: Instantaneous Field of View
IPF: Image Processing Facility
IR: Infrared
IRIS: Infrared Interferometer Spectrometer

JPL: Jet Propulsion Laboratory (Pasadena, Calif.)

LAPR: Linear Array Pushbroom Radiometer
LARS: Laboratory for Applications of Remote Sensing (W. Lafayette, Ind.)
LUDA: Land Use and Data Analysis (System)

MLA: Multilinear Array
MMS: Multi-Modular Satellite
MSS: Multispectral Scanner

NASA: National Aeronautics and Space Administration
NCIC: National Cartographic Information Center
NESS: National Earth Satellite Service
NIR: Near Infrared
NOAA: National Oceanic and Atmospheric Administration

OCS: Ocean Color Scanner
OMB: Office of Management and Budget
ORSER: Office of Remote Sensing of Earth Resources (Pennsylvania State University)

PCA: Principal Components Analysis
PFRS: Portable Field Reflectance Spectrometer
PP&L: Pennsylvania Power and Light (Company) (Allentown, Pa.)

RA: Rural Area
Radar: Radio Detection and Ranging
R&D: Research and Development
RBV: Return Beam Vidicon
RJE: Remote Job Entry

SAR: Synthetic Aperture Radar
SCMR: Surface Composition Mapping Radiometer
SEOS: Synchronous Earth Observations Satellite
SLAR: Side-Looking Airborne Radar
SMS: Synchronous Meteorological Satellite
SMSA: Standard Metropolitan Statistical Area
S/N: Signal to Noise
SOM: Space Oblique Mercator
SWIR: Short Wave Infrared

TDRS: Tracking and Data Relay Satellite
TIR: Thermal Infrared
TIROS: Television Infrared Observation Satellite
TM: Thematic Mapper

UA: Urban Area
USGS: United States Geological Survey
UTM: Universal Transverse Mercator
UV: Ultraviolet

VI: Vegetation Index
VICAR: Video Image Communication and Retrieval (System)

WRAP: Western Regional Applications Center (Moffett Field, Calif.)

ZTS: Zoom Transfer Scope

Appendix D

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Appendix E

ERL Rpt. Number	Date	Author	Title
167	3/78	Junkin	A Procedure for Extraction of Disparate Data from Maps Into Computerized Data Bases
168	7/5/78	K. Butera	A Demonstration of Wetland Vegetation Mapping in Florida from Computer-Processed Satellite and Aircraft Multispectral Scanner Data
169	8/1/78	K. Butera	A Determination of the Optimum Time of Year for Remotely Classifying Marsh Vegetation From Landsat Multispectral Scanner Data
170	3/78	Wolverton McDonald	Water Hyacinth Absorption Rates of Lead, Mercury and Cadmium
171	3/78	Wolverton McDonald	Water Hyacinth (Eichhornia crassipes) Productivity and Harvesting Schedules
172	3/78	Wolverton McDonald	Upgrading Facultative Waste Stabilization Ponds with Vascular Aquatic Plants
173	3/78	Wolverton McDonald	Nutritional Composition of Water Hyacinths Grown on Domestic Sewage
174	3/78	Joyce	Natural Resources Inventory Final Report
175	12/13/78	K. Faller	Shoreline as a Controlling Factor in Commercial Shrimp Production
176	12/14/78	J. Anderson	Western Energy Related Overhead Monitoring Project; Phase II Summary
177	1/17/79	B. Junkin	A Method for the Processing, Analysis and Application of Digital Terrain Elevation Data
178	1/19/79	B. Baumann	Evaluation of Three Techniques for Classifying Urban Land Cover Patterns Using Landsat MSS Data
179	5/2/79	J. Anderson	Multistage Variable Probability Forest Volume Inventory
180	7/29/79	W. Cibula	Computer-Implemented Land Cover Classification Using Landsat MSS Digital Data
181	11/5/79	Joyce/ Cashion/ Ivey	An Evaluation of Techniques for Deriving Information from Landsat MSS Digital Data

ERL Rpt. Number	Date	Author	Title
182	2/80	Anderson	Analysis of Results Obtained from Computer-Implemented Land Cover Classifications Produced from Single Season and Multitemporal Landsat MSS Data
183	3/21/80	Graham	Earth Resources Laboratory Applications Software (ELAS)
184	5/19/80	Joyce	Use of Landsat MSS Data for Detecting Land Cover Changes
185	7/1/80	Junkin	Scientific Analysis Software on the NASA/ERL Computer System
186	8/5/80	Junkin	A Regression Analysis Procedure for Verification of Digitizer System Accuracy Specifications
187	8/20/80	Cibula	Computer-Implemented Land Cover Classification Using Landsat MSS Digital Data: A Cooperative Research Project Between the NPS and NASA; II, Geologic & Vegetation Analysis of Death Valley National Monument
188	8/21/80	Anderson	Analysis of Results Obtained from Computer-Implemented Land Cover Classifications Produced from 3-Seasons Data
189	9/2/80	Wu	Analysis of the Results Obtained by Merging Landsat Multispectral Scanner Data with Seasat Synthetic Aperture Radar Data
190	9/3/80	Anderson	The Integration of Two Signature Development Techniques for the Delineation of Forest Cover Types in Southeast Louisiana
191	9/3/80	Anderson	Western Energy Related Overhead Monitoring Project; III Summary
192	9/16/80	Wolverton	Higher Plants for Recycling Human Waste into Food, Potable Water, and Revitalized Air in a Closed Life Support System
193	10/7/80	Cibula	Computer-Implemented Land Cover Classification Using Landsat MSS Digital Data: A Cooperative Research Project Between the NPS and NASA; III, Geologic & Vegetation Analysis of Olympic National Park

ERL Rpt. Number	Date	Author	Title
194	10/7/80	Cibula	Computer-Implemented Land Cover Classification Using Landsat MSS Digital Data: A Cooperative Research Project Between the NPS and NASA; III, Geologic & Vegetation Analysis of Shenandoah Valley
195	11/6/80	Junkin	Three-Dimensional Prospective Software for Graphics Display
196	5/12/80	Graham/ Junkin/ Kalcic	AgRISTARS - Domestic Crops & Land Cover - Evaluation of Multiband, Multitemporal & Transformed Landsat MSS Data for Land Cover Area Estimation
197	5/12/80	Graham/ Luebbe	AgRISTARS - Domestic Crops & Land Cover - An Evaluation of MSS P-Format Data Registration
198	10/6/81	Seyfarth	Analysis of Landsat MSS Scene-to-Scene Registration Accuracy
199	10/16/81	Cibula	Utilization of Landsat Multispectral Data in Geobotanical Investigations
200	11/17/81	Junkin	Conversion of Map-Based Spatial Data to a Digital Format Using an On-Line Digitizer System
201	12/2/81	Graham	An Algorithm for Automating Registration of USDA Segment Ground Data to Landsat MSS Data
202	12/3/81	Anderson	Analysis of Thematic Mapper Simulator Data for the Winter Season for the Pearl River MS Test Site
203	1/21/82	Dow/Kalcic	Noise Removal by Principal Component Analysis
204	1/26/82	Anderson	An Analysis of Thematic Mapper Simulator Data Collected During the Fall Season over Eastern North Dakota
205	3/17/82	Stoner	Agricultural Land Cover Mapping in the Context of a Geographically Referenced Digital Information System
206	3/18/82	Quattrochi	A Technique for Using Multi-Date Landsat MSS Data for the Discrimination of Small Heterogeneous Surface Mine Features in Eastern Kentucky

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207	3/24/82	Wu	The Analysis of Data Acquired by the Synthetic Aperture Radar & Landsat Multispectral Scanner over Western Kentucky Coal Region
208	4/14/82	Dow	SLIN - A Software Program to Measure Interface Length
209	6/30/82	Kalcic	Automatic Segment Matching Algorithm Theory Test and Evaluation
210	7/26/82	Dow	Software Programs to Measure Interface Complexity with Remote Sensing Data
211	7/26/82	Musick	Analysis of Dry Season Thematic Mapper Simulator and Landsat Multispectral Scanner Data for Jornada Test Site
212	10/7/82	Butera	A Correlation Analysis of Percent Canopy Closure vs TMS Spectral Response for Selected Forest Sites in San Juan Forest, Col.
213	10/12/82	Wu	Analysis of Data Acquired by Synthetic Aperture Radar and Landsat Multi-Spectral Scanner over Kershaw Co. South Carolina during Summer Season
214	11/2/82	Anderson	Mid/Thermal IR Remote Sensing-FY82 RTOP #677-21-21 Summary Report
215	11/19/82	Quattrochi	An Analysis of Landsat 4 Thematic Mapper Data for the Classification of Agriculture, Forested Wetland and Urban Land Covers
216	12/20/83	Cibula	Temporal Spectral Investigation of Several Gramineae from Full Turgor to Reduced Turgor Condition as a Result of Water Deprivation
217	11/22/82	Anderson	Determining Map Accuracy Based on the Use of USDA Statistical Reporting Service - June Enumerative Survey Segment Data
218	2/2/83	Wu	Analysis of Data Acquired by Synthetic Aperture Radar over Dade County, Florida and Acadia Parish, Louisiana
219	3/4/83	Junkin	A Geobased Information System Providing Applications Based on Landsat/MSS Data

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220	3/18/83	Rickman	The Mt. Emmons, Colorado Geology Study Site Acquisition and Computer Processing of Airborne Thematic Mapper Simulator Data for a Mountainous, Partially Vegetated Area
221	5/17/83	Burns	Land Cover Change Monitoring within the East Central Louisiana Study Site. A Case for Large Area Surveys with Landsat Multispectral Scanner Data
222	6/16/83	Anderson	The Use of Landsat-4 MSS Digital Data in Temporal Data Sets and the Evaluation of Scene-to-Scene Registration Accuracy
223	7/29/83	Brannon	Water Resources Management Applications of Landsat Multispectral Scanner Data
224	9/8/83	Stoner	Stratification of Sampled Land Cover by Soils for Landsat-Based Estimation & Mapping
225	9/15/83	May	Classification and Area Estimation of Land Covers in Kansas Using Ground Gathered and Landsat Digital Data
226	10/12/83	Brannon	Crop Mensuration and Mapping Joint Research Project Interim Report
227	12/14/83	Sever	Feasibiity Study to Determine the Utility of Advanced Remote Sensing Technology in Archeological Investigations
228	7/9/84	Wu	Analysis of Data Acquired by Shuttle Imaging Radar and Landsat-4 TM over Baldwin County, Alabama
229	9/14/84	Sader	Thermal Differences in Reforested Clearcuts and Old Growth Forests on Mountain Terrain
230	9/14/84	Sader	Relationship Between Forest Clearing and Biophysical Factors in Tropical Environments
231	1984	Anderson	Preprocessing Thematic Mapper Digital Data for Dimensionality Reduction
232	11/7/84	Uribe	Land Cover Classification Using Landsat Thematic Mapper Data in Southern Louisiana and Mississippi